In cooperation with Lac Vieux Desert Band of Lake Superior Chippewa Indians

Water Quality and Hydrology of the Lac Vieux Desert Watershed, Gogebic County, Michigan, and Vilas County, Wisconsin, 2002-04

Scientific Investigations Report 2005-5237

U.S. Department of the Interior
U.S. Geological Survey

Cover Photograph. Lobischer Creek. Gogebic County, Michgan. (Photograph courtesy of Thomas Pietila, Lac Vieux Desert Band of Lake Superior Chippewa Indians.)

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Conversion Factors, Abbreviations, and Vertical Datum

Multiply	By	To obtain
	Length	
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare (ha)
	Flow rate	
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8.
Runoff
Runoff is the quantity of water that is discharged, or “runs off” from a drainage basin during a given time period. Runoff data in this study are reported as mean discharge per unit of drainage area in cubic feet per second per square mile ($ft^3/s/mi^2$).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L), micrograms per liter (µg/L), or nanograms per liter (ng/L). For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

MI and WI are U.S. Postal Service codes for Michigan and Wisconsin, respectively.

The symbol < means less than; the symbol > means more than.

Vertical Datum
In this report, altitude or elevation refers to vertical distance above the National Geodetic Vertical Datum of 1929 (NGVD 29)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called sea level Datum of 1929.

Water Quality and Hydrology of the Lac Vieux Desert Watershed, Gogebic County, Michigan, and Vilas County, Wisconsin, 2002-04

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Abstract

Lac Vieux Desert is a prominent 6.6 square-mile lake that straddles the Michigan-Wisconsin border and forms the headwaters of the Wisconsin River. For generations, the Lac Vieux Desert Band of Lake Superior Chippewa Indians have used Lac Vieux Desert and the surrounding area for growing and harvesting wild rice, and hunting and fishing. The Lac Vieux Desert Band is concerned about the impact of lake-stage regulation on hydrology and ecology, and the impact on water quality of development along and near the shore, and recreational watercraft use and sport fishing. In 2005, the U.S. Geological Survey completed a water-resources investigation of the Lac Vieux Desert watershed in cooperation with the Lac Vieux Desert Band of Lake Superior Chippewa Indians.

Water quality of Lac Vieux Desert is typical of many lakes in the northern United States. Trophic State Index calculations classify Lac Vieux Desert as a highly productive eutrophic lake. The pH of water in Lac Vieux Desert ranged from 6.5 to 9.5, and specific conductance ranged from 62 to 114 µs/cm. Chloride concentration was less than 1.5 mg/L, indicating little effect from septic-tank or road-salt input. Results indicate that the water can be classified as soft, with hardness concentrations reported as calcium carbonate ranging from 29 to 49 mg/L. Concentrations of calcium, magnesium, chloride, and other dissolved solids ranged from 47 to 77 mg/L. Alkalinity of Lac Vieux Desert ranged from 27 to 38 mg/L.

Pervasive aquatic blooms, including a bloom noted during the September 2003 sampling, are apparently common in late summer. Biological productivity at Lac Vieux Desert does not appear to have changed appreciably between 1973 and 2004. In the current study, total phosphorus concentrations ranged from 0.01 to 0.064 mg/L and dissolved nitrite plus nitrate nitrogen concentrations ranged from at, or below detection limit to 0.052 mg/L. Overabundance of nutrients in Lac Vieux Desert, particularly nitrogen and phosphorus, could result in considerable degradation in lake-water quality.

The estimated water balance includes the following inputs from the surrounding watershed: direct precipitation (35 percent); runoff, composed of streamflow and overland flow (50 percent); and ground-water flow (15 percent). Outputs from Lac Vieux Desert include streamflow into the Wisconsin River (68 percent) and evaporation from the lake surface (32 percent). Seasonal regulation of Lac Vieux Desert outflow results in an artificially high lake stage throughout the year, except from late winter to very early spring, prior to snowmelt and runoff. Regulation of Lac Vieux Desert outflow causes Wisconsin River streamflow to be artificially low during spring and summer and artificially high in fall and winter.

Recent studies indicate that lake-level regulation over the past century may have affected wild rice growth and propagation in Lac Vieux Desert. As per licensing agreement between the Federal Energy Regulatory Commission and the Wisconsin Valley Improvement Company (operators of the dam at the outlet), the maximum lake level of Lac Vieux Desert was lowered about 0.8 feet to investigate the relation between lake-level regulation and propagation of wild rice from 2003 through 2012. Recent plantings of wild rice by the Lac Vieux Desert Band have been successful, indicating that suitable habitat and hydrologic regime were present in 2004-05.

Introduction

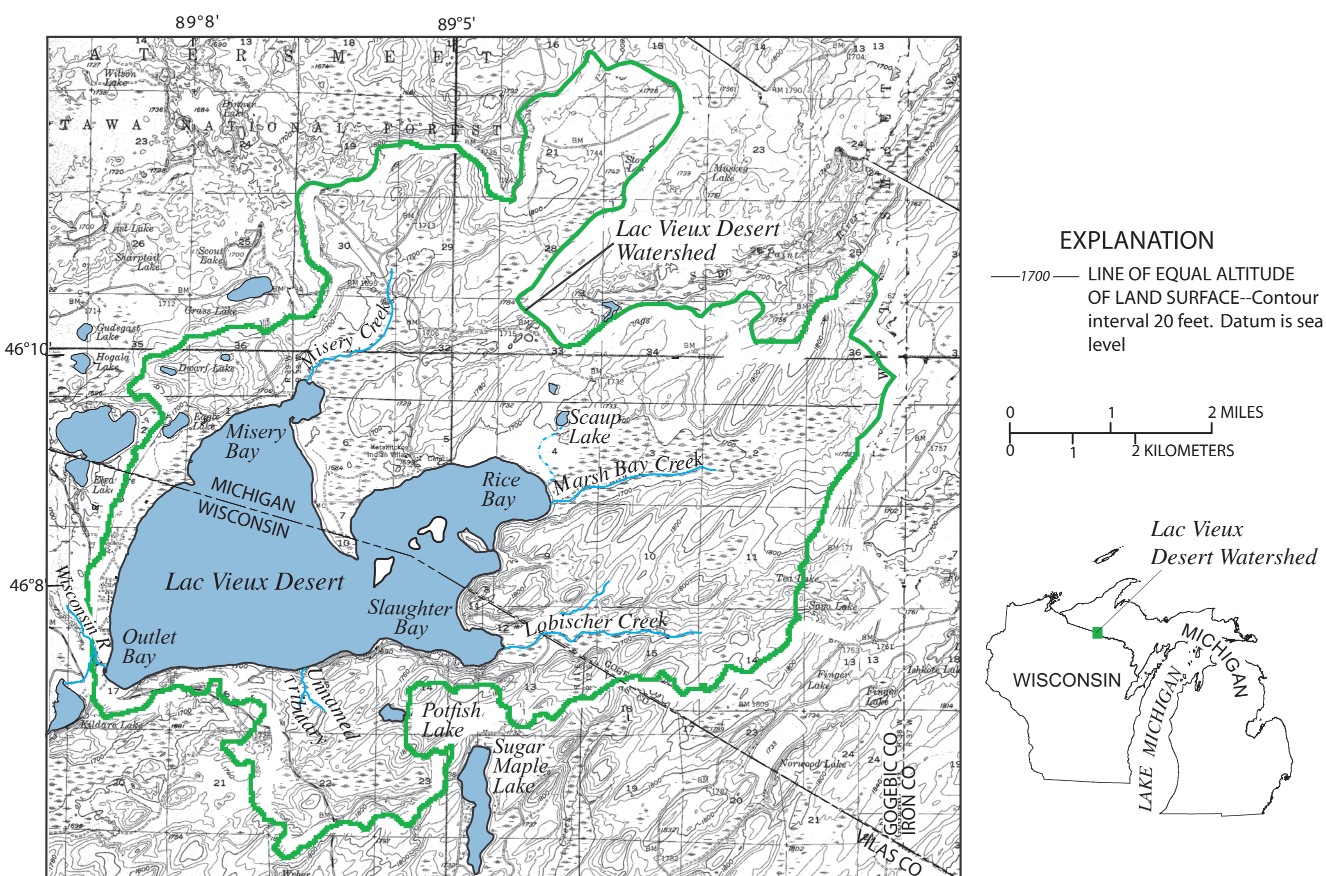
Lac Vieux Desert (LVD) is a prominent lake in southeastern Gogebic County, Michigan, and northern Vilas County, Wisconsin (fig. 1). Water-resource management issues at LVD result from diverse and sometimes conflicting uses of the lake. Water resources at LVD are an important part of the cultural heritage of the Lac Vieux Desert Band of Lake Superior Chippewa Indians (LVD Band), provide hydroelectric power at downstream locations, and support a local recreation-based economy. The LVD watershed has historically been used by the LVD Band for cultivating wild rice, hunting, and fishing. Since the late 1800's, the lake level (stage) of LVD has been regulated for logging and hydroelectric power generation downstream, more recently there has been considerable development of the LVD shoreline for privately owned residences and resorts.

Concerns of LVD Band members include the effects of shoreline development and recreational watercraft use on water quality, and regulation of LVD lake stage and outflow and its impact on wild-rice propagation (George Beck, Lac Vieux Desert Band, written commun., 2005). To evaluate the water resources of the LVD watershed and address LVD Band concerns, the U.S. Geological Survey (USGS), in cooperation with the LVD Band, conducted a study of the watershed during 2002-04 and results of that data-collection effort comprise most of this report.

Purpose and Scope

The purpose of this report is to (1) compare trophic-status indices from the current study with historical trophic-status indices collected by various entities over the past three decades, (2) establish a baseline surface-water quality database for 2002-04, (3) document Wisconsin River streamflow at the outlet and LVD lake stage, (4) estimate a water balance for LVD, and (5) discuss the hydrological and ecological effects of lake-stage regulation. Construct a net basin supply model and summarize wild-rice restoration efforts.

Data from previous studies were used to augment the present study and provide a historical context for the watershed. Data collected during this study (2002-04) include streamflow into and out of the lake; lake-stage data; and field water-quality parameters and water-quality samples at seven sites previously sampled in 1996 (Barton and Grannemann, 1998) and at three new sites (all sites on LVD). A water balance was constructed using streamflow data collected as part of this study and available data from the LVD watershed and other nearby lakes. The water balance is useful for resource managers and others interested in the magnitude and type of inputs and outputs presently impacting the LVD watershed. A net basin supply model was constructed for LVD to estimate streamflow from the outlet and lake stage in the absence of regulation. Wild-rice restoration efforts and the effects of lake-stage regulation are briefly summarized using recent data (2000-04) and aerial photographs supplied by Great Lakes Indian Fish & Wildlife Commission (GLIFWC).



Background from USGS 1:24,000 topographic maps. Watershed boundary derived from National Elevation Dataset 1:24,000.

Figure 1. Location of Lac Vieux Desert study area, Gogebic County, Michigan, and Vilas County, Wisconsin.

Previous Studies and Data-Collection Efforts

An appreciable body of research has been conducted in the LVD watershed. A previous study by Barton and Grannemann (1998) describes the surface- and ground-water hydrology of the nearshore area LVD and lake-water quality. Barton and Grannemann (1998) measured field water-quality parameters and collected nutrient samples at 3 sites in March 1996 and at 10 sites in October 1996. WVIC monitors inflow to LVD and outflow at the dam regularly. Also, WVIC measured field water-quality parameters at the dam and in the deepest part of the lake from 1973 though 1989. From 1979 through 1983, WVIC also sampled the deepest part of the lake for nutrients, turbidity, and additional chemical constituents. From 2000 through 2002, WVIC again sampled the deepest part of the lake for field water-quality parameters and chlorophyll-*a*. Michigan Department of Natural Resources (MDNR) and Michigan Department of Environmental Quality (MDEQ) measured field water-quality parameters and sampled for chemical data in LVD in 1981 and 1994 (U.S. Environmental Protection Agency STORET site number MI 860017). USGS sampled water quality at the deepest subbasin of LVD twice in 2003 for MDEQ's Inland Lakes Study (Minnerick, 2004). A component of the MDEQ study investigated trophic status of LVD with a qualitative cataloging of macrophytes and their abundance at 4 sites around the lake.

Description of the Study Area

LVD and its watershed comprise 34.4 mi^2 on the border of the Upper Peninsula of Michigan and northern Wisconsin (fig. 1). LVD and its tributaries are the headwaters of the Wisconsin River (fig. 2), which flows about 400 mi to the Mississippi River, and, ultimately, the Gulf of Mexico. LVD is a natural-lake reservoir, meaning that it is a natural lake but has been altered by installing a dam at the natural outlet; a photograph of the lake taken from the dam site is shown in figure 3. The lake has a mean elevation of 1,680 ft above NGVD 29 and a surface area of 6.6 mi^2. Fishing Hot Spots (1992) indicates that nearly 76 percent of the lake is less than 15 ft deep and lists the maximum depth of the lake as 43 ft. Wisconsin Department of Natural Resources (2005) lists the maximum depth as 38 ft and Wisconsin Valley Improvement Company (2005) lists the maximum depth as 42 ft. A bathymetry map of the lake is shown in figure 4, but it excludes a 40-ft contour in the deepest basin because it was not delineated on the WDNR or MDNR base maps.

Lake stage at LVD is artificially controlled by a small dam at the southwestern corner of the lake (fig. 4). Barton and Grannemann (1998) indicated that a wooden dam was first constructed at the LVD outlet in the 1870's. The dam has been owned by Wisconsin Valley Improvement Company (WVIC) since 1907 and they maintain historical documentation dating to June 1891, when a wooden dam was licensed and constructed. In 1937, the wooden dam was replaced by the current concrete and steel structure, which is capable of precisely regulating the lake stage and river flow. Passage of migrating fish is also possible with the current structure by simply adding or removing boards in the fishway. The dam at LVD is operated in accordance with Federal Energy Regulatory Commission (FERC) guidelines. WVIC operates additional dams and reservoirs and manages the flow of the Wisconsin River Valley for hydroelectric power generation needs as far downstream as the eastern end of the Wisconsin Dells, WI (fig. 2).

Land-surface elevations in the watershed range from about 1,681 ft at the lakeshore to as much as 1,865 ft above NGVD 29 on hills southeast of the lake (fig. 1). Topography of the area on the west side of the lake is considerably lower-lying and has less relief than most of the remainder of the watershed. Although flat-lying areas compose part of the watershed, most of the watershed can be described as rolling and hilly. Pleistocene glaciation, specifically during the late-Wisconsinan period (from approximately 25,000 to 10,000 years before present), has greatly affected current landforms in the watershed, although Holocene (postglacial) organic deposits are present in most drainage basins of streams tributary to the lake.

Sedimentation into LVD is low for two reasons. First, the drainage area (watershed) of the lake is relatively small compared to the size of the lake itself, limiting the area from which sediment can be drawn. Second, the forested upland and swampy downstream parts of the drainage area are not conducive to erosion and sedimentation. All five of the tributary streams enter low-gradient (10 ft/mi or less) wetlands prior to reaching the lake, effectively sequestering much of the sediment that would reach a lake in their absence.

Land use in the study area is summarized in table 1. No major cities are located within or near the study area, although the village of Land O' Lakes (fig. 2) is about 3.5 mi west of the lake. Almost the entire watershed is composed of either forested land or water and wetlands, with little development. Low-density residential development is occurring along roads and near the lakeshore.

The LVD Band owns 86 acres adjacent to Rice Bay on the north shore of LVD, on which they have developed housing units, a park, and a fish hatchery. The LVD Band also owns 276 acres in a remote area along Lobischer Creek and adjacent to Slaughter Bay on the southeastern side of the lake (fig. 4).

Climate

Climate data have been collected near LVD since the 1940's. Precipitation and snow depth on the south shore of LVD just west of the unnamed tributary (fig. 4) have been measured since 1946 by a National Oceanic and Atmospheric Administration (NOAA) cooperative climate observer (station 474383). Another NOAA cooperative climate station near Eagle River, WI (station 472314), (fig. 2) has been active since 1948. The Eagle River station records air temperature, precipitation, and snow depth. A third source of weather data is the North Temperate Lakes research project site near Trout Lake,

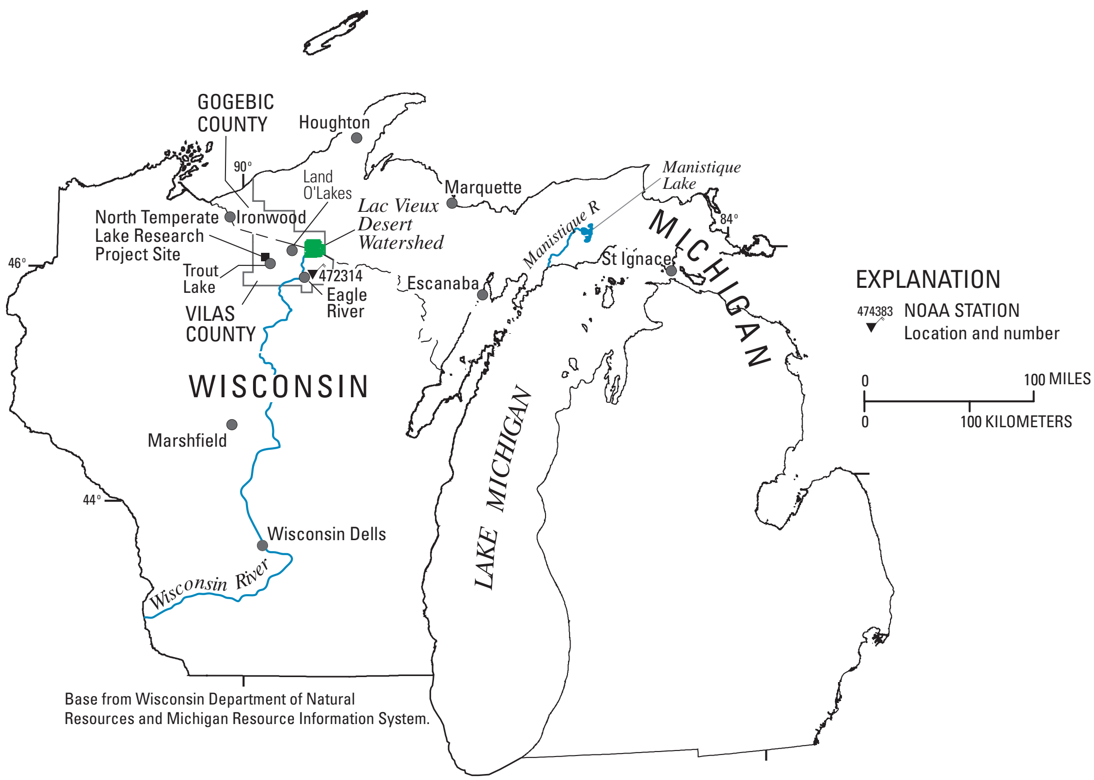


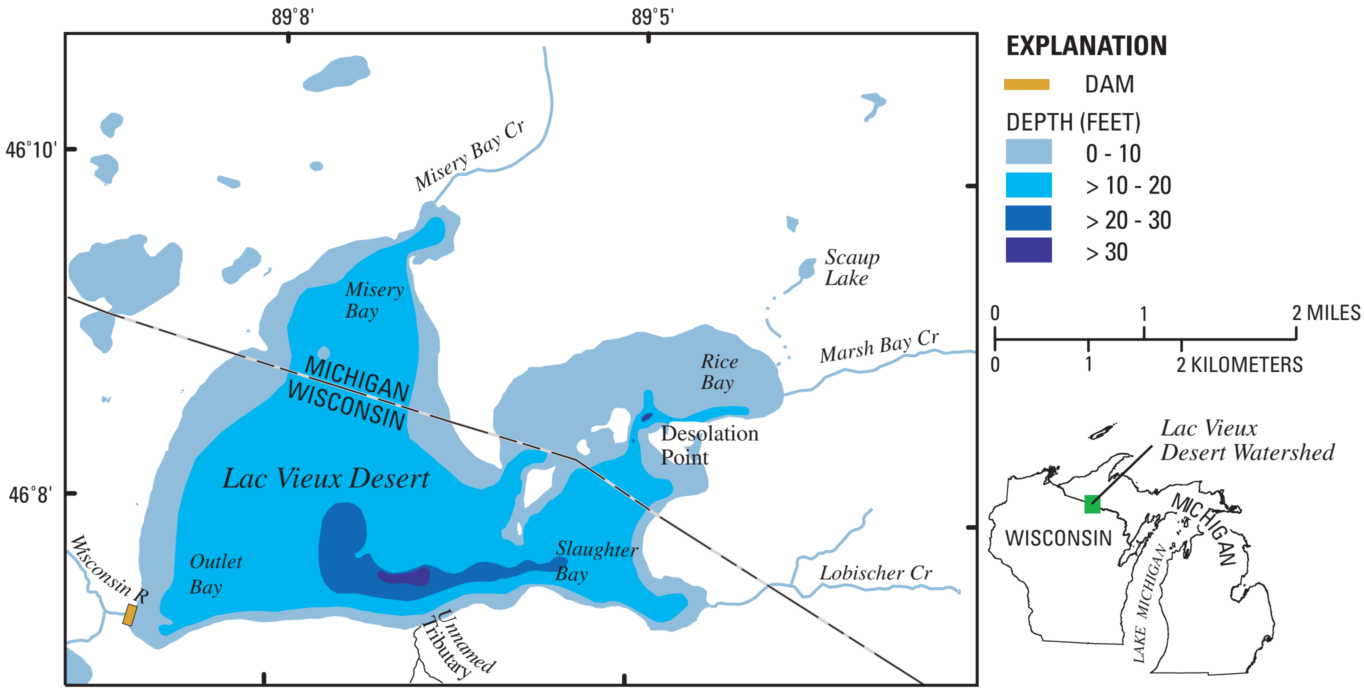
Figure 2. Locations of Lac Vieux Desert watershed, other surface-water features, and selected Michigan and Wisconsin cities and villages.

Figure 3. Photograph showing Lac Vieux Desert, Gogebic County, Michigan, and Vilas County, Wisconsin, looking east from dam site at the outlet along the south shore, May 2005. Photograph by Stephen Horton, U.S. Geological Survey.

WI, approximately 25 mi southwest of LVD (fig. 2). Climate parameters have been measured at the Trout Lake site from 1989 through 2004.

The climate of the LVD study area is typical of the northern Great Lakes Basin. Mean annual precipitation for the years 1971-2000 is 33.8 in. (National Climate Data Center, 2002). Seasonal variability of precipitation at LVD is appreciable. Most precipitation falls from June through September, and the least precipitation typically falls from December through March. The comparison between monthly precipitation for 2002-03 and 30-year monthly mean precipitation is shown in table 2. Mean air temperature for the years 1971-2000 is about 40^{O}F (National Climate Data Center, 2002). The comparison between monthly mean temperatures for 2002-03 and 30-year monthly mean temperature is shown in table 3. In 2002, the study area received about 7.3 in. more precipitation than normal and had near-normal temperatures, while in 2003, precipitation was 2.2 in. below normal and temperatures were 1.4^{O}F below normal.

Evaporation data for the area are available from various



Wisconsin hydrologic features and state boundary from Wisconsin Department of Natural Resources. Michigan hydrologic features and state boundary from Michigan Resource Information System. Bathymetry data from Institute for Fisheries Research, Michigan Conservation Department, 1954.

Figure 4. Bathymetry of Lac Vieux Desert, Michigan and Wisconsin. (>, greater than)

sources, although none of the data are specific to LVD. Various studies of pan evaporation and floating-pan evaporation for lakes near LVD, including Rainbow Reservoir in Oneida County immediately south of Vilas County, have been completed. Estimates of evaporation from these nearby lake studies ranged from about 22 to 23 in/yr for the 184-day period from May through October. (Wentz and Rose, 1991; Robertson and others, 2003).

Geologic and Hydrologic Setting

The land-surface features in southeastern Gogebic and northern Vilas Counties are affected by the Precambrian bedrock and unconsolidated glacial deposits, which overlie the bedrock (Doonan and Hendrickson, 1968). Topography of the study area (fig. 1) ranges from relatively flat-lying wetland and recent alluvial deposits, outwash deposits, and till plains, to drumlins and moraines that rise as much as 160 ft above the lake surface. Drumlins and moraines, which are interspersed with thin bands of swampy alluvial deposits, border much of the shoreline on the northern, eastern, and southern shores of LVD, whereas thick outwash deposits and swampy areas are more typical of the western shore (fig. 5). Two aquifers composed of unconsolidated sediments are found in nearshore areas along the north shore. The aquifers, which are thought to be the only source of drinking water near the lake, are an upper unconfined, or water-table unit; and a less well-defined (as compared to the upper unit), lower confined unit that is overlain by a clay confining layer (Barton and Grannemann, 1998).

Glacial sediments

With the exception of some areas where bedrock outcrops at the land surface, landforms created by glacial advance and wastage are the predominant geomorphologic features of the present-day Upper Peninsula of Michigan and northern Wisconsin, including Gogebic and Vilas Counties near LVD. The glacial history of the study area is complex, similar to most other glaciated areas of the Upper Midwest. Based on many studies, multiple episodes of Wisconsinan glaciation are known to have occurred in the study area. Earlier (pre-Wisconsinan) glacial advances also covered the study area, but glacially derived sediments, which compose most of the present-day unconsolidated deposits overlying bedrock in the study area, are primarily attributed to late Wisconsinan readvances (Attig, 1985). As the ice advanced from the present-day Lake Superior and Lake Michigan Basins, it formed into lobes and flowed south and west. Three lobes are known to have covered parts of Vilas County during this period: the Langlade

Table 1. Land use in the study area, Gogebic County, Michigan, and Vilas County, Wisconsin (U.S. Environmental Protection Agency, Office of Water/OST, 1998).

[Numerical values in the table are rounded and total is not exactly 100 percent]

Land-use type	Percentage of study area
Forested	59.8
Water	23.1
Wetland	15.7
Barren land	.23
Developed	.7
Rangeland	.5
Agricultural	.02

and Wisconsin Valley Lobes occurred first, followed by the Ontonagon Lobe, which overrode the northern parts of the other two lobes as they were wasting. Attig (1985) describes in detail the mineralogy, sedimentology, stratigraphy, and relative positions of the various glacial units in Vilas County.

The glacial geology of the study area is shown in figure 5. Landforms south and east of LVD are primarily west- to southwest-trending drumlins primarily composed of coarse-grained till, interspersed with some postglacial organic deposits. Organic deposits constitute much of the nearshore area along Rice Bay. The shoreline near the LVD outlet in the southwestern corner of the lake is composed of glacial outwash or braided stream sediments in plains. The drumlin morphology and stream sediments near the outlet are interpreted as derived from the Langlade Lobe. Surficial deposits on the west and northwest side of LVD are interpreted as braided stream sediments derived from the Ontonagon Lobe.

Attig (1985) indicates that the landscape of Vilas County has undergone relatively little change since the final Wisconsinan advance around 10,000 years ago. The most obvious change, however, is the development of soils. The permeable nature of much of the sediment package in the study area insures that infiltration is rapid and inhibits the development of a well-defined drainage system.

Bedrock

Precambrian rock is known to outcrop in only two places in Vilas County, west and south of the study area (Attig, 1985). Barton and Grannemann (1998) showed that the bedrock surface along the north shore of LVD is about 120 ft below the surface of the lake. Because of its effect on the composition of glacial sediments, bedrock north and northeast of the study area had a greater effect on the study area than the underlying bedrock itself. The source areas for sediments entrained by the glacial lobes are inferred from the flow direction of the lobes, as well as composition of the present-day sediment packages.

Methods of Investigation

A Quality-Assurance Program Plan (QAPP) was prepared by USGS and LVD Band environmental staff, and approved by the USGS NWQL and the U.S. Environmental Protection Agency (USEPA) before data collection began.

Water-Quality Sampling

All water-quality sampling was done using standard techniques described in the U.S. Geological Survey “National Field Manual for the Collection of Water-Quality Data” (variously dated). All samples were analyzed at NWQL, except mercury samples, which were analyzed at the USGS Wisconsin Water Science Center Mercury Laboratory. All quality-assurance/quality-control samples were collected and analyzed in accordance with USGS guidelines and the QAPP.

Spring sampling preceded potential lake stratification and fall sampling preceded turnover. A boat was used as a sampling platform for all the sites except the Wisconsin River outlet (station 05390100; fig. 6). Field water-quality parameters were measured using a multiparameter meter. At the Wisconsin River outlet, all samples were collected using a hand-held sampler. At all other sites, samples were collected in a suspended Van Dorn sampler (Franson, 1998) except samples for chlorophyll-*a*, which were collected in a weighted sampler specifically designed for that purpose and used for the MDEQ Inland Lakes Study (Minnerick, 2004).

Water clarity (transparency of water to light) was measured with a Secchi disk. The white and black disk was lowered into the lake until it disappeared, and then raised until it was again visible, indicating the depth that sunlight penetrated the water column. Light penetration, which is crucial to photosynthesis, determines to some degree the composition of algae and rooted plants within a lake and is used in calculation of trophic state indices.

In 2002 and 2003, USGS collected 14 water-quality samples at 7 sites that were also sampled in 1996 (Barton and Grannemann, 1998). In 2004, eight additional samples were collected at four sites (only one site had been previously sampled). Samples collected in 2002 and 2003 were analyzed for concentrations of major elements, solids, nutrients, turbidity, and chlorophyll-*a*. In 2004, the sampling routine was refined with sampling concentrated on nutrients and chlorophyll-*a* at the outlet and site 15 (in the middle of Rice Bay), and additional sampling within the water column at site 5A and site 14 (in the deepest part of Misery Bay) (fig. 6).

Water-Quality Reporting Levels

The NWQL has established reporting levels for various analytical procedures (Bollinger Childress and others, 1999). In the following sections, tabulated data are reported as “uncensored,” “censored,” or estimated. Uncensored data are data

Table 2. Monthly precipitation recorded at Lac Vieux Desert, Wisconsin, in 2002-03, compared to 1971-2000 monthly mean precipitation (Brian Hahn, National Oceanic and Atmospheric Administration, written commun., 2004).

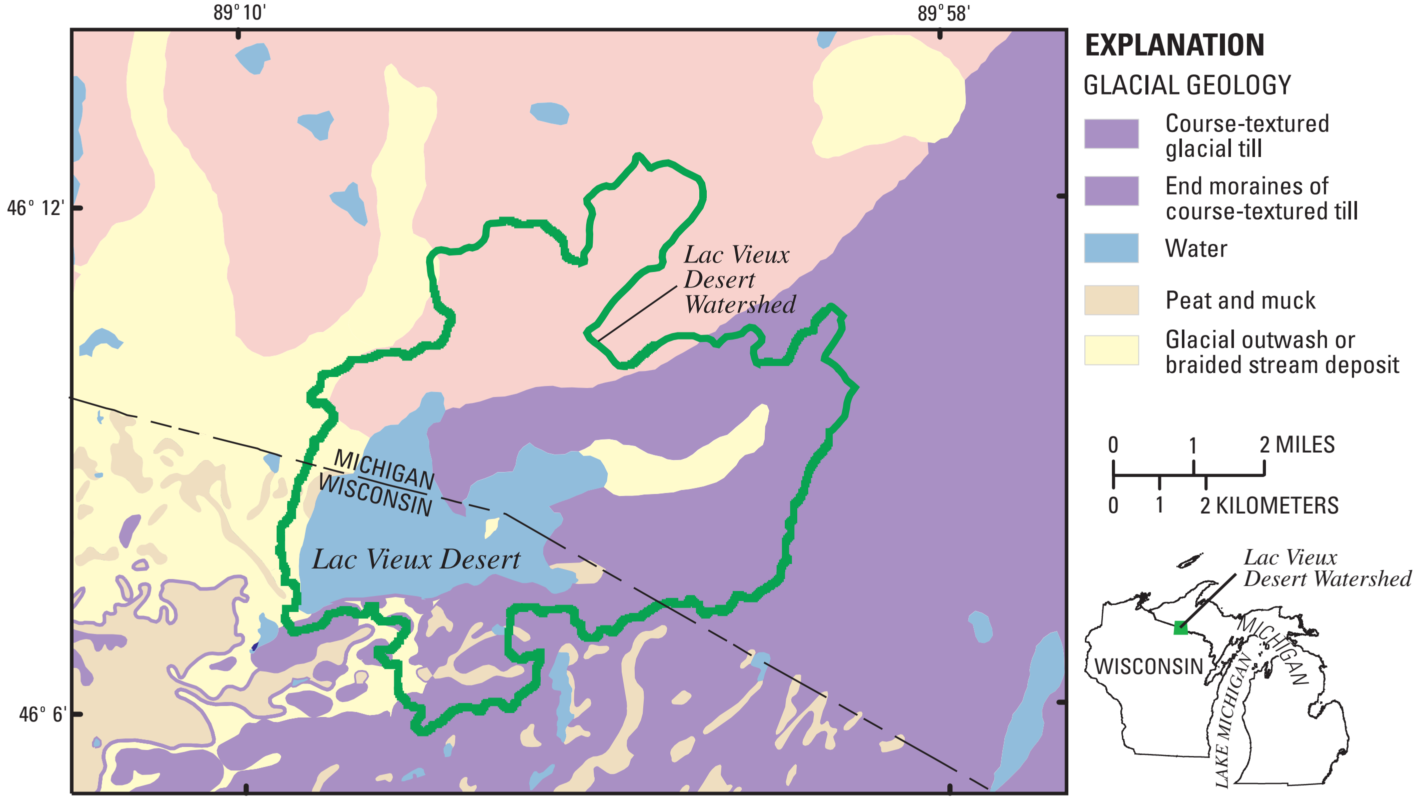
[All precipitation values are in inches]

MONTH	1971-2000 MONTHLY MEAN PRECIPITATION	2002 MONTHLY PRECIPITATION	DEPATURE OF 2002 MONTHLY PRECIPITATION FROM THE 1971-2000 MONTHLY MEAN PRECIPITATION	2003 MONTHLY PRECIPITATION	DEPATURE OF 2003 MONTHLY PRECIPITATION FROM THE 1971-2000 MONTHLY MEAN PRECIPITATION
JAN.	1.60	0.47	-1.13	0.58	-1.02
FEB.	1.09	2.36	1.27	.91	-.18
MAR.	2.00	3.21	1.21	2.09	.09
APR.	2.29	5.00	2.71	3.63	1.34
MAY	3.29	3.47	.18	5.55	2.26
JUNE	4.35	4.71	.36	1.95	-2.40
JULY	4.09	5.16	1.07	3.20	-.89
AUG.	4.16	4.39	.23	3.39	-.77
SEPT.	4.00	5.07	1.07	3.63	-.37
OCT.	2.88	5.43	2.55	2.45	-.43
NOV.	2.45	1.18	-1.27	2.82	.37
DEC.	1.63	.65	-.98	1.41	-.22
TOTAL	33.83	41.10	7.27	31.61	-2.22

Table 3. Monthly mean temperatures recorded at Eagle River, Wisconsin, in 2002-03, compared to 1971-2000 monthly mean temperatures (Brian Hahn, National Oceanic and Atmospheric Administration, written commun., 2004).

[All temperatures are in degrees Fahrenheit]

MONTH	1971-2000 MONTHLY MEAN TEMPERATURE	2002 MEAN-MONTHLY TEMPERATURE	DEPATURE OF 2002 MEAN-MONTHLY TEMPERATURES FROM THE 1971-2000 MONTHLY MEAN TEMPERATURES	2003 MEAN-MONTHLY TEMPERATURE	DEPATURE OF 2003 MEAN-MONTHLY TEMPERATURES FROM THE 1971-2000 MONTHLY MEAN TEMPERATURES
JAN.	10.4	19.4	9.0	8.9	-1.5
FEB.	15.6	20.6	5.0	7.3	-8.3
MAR.	25.4	17.8	-7.6	22.2	-3.2
APR.	39.7	37.5	-2.2	36.1	-3.6
MAY	53.2	47.4	-5.8	51.0	-2.2
JUNE	63.0	64.4	1.4	61.3	-1.7
JULY	66.6	71.3	4.7	66.6	0
AUG.	64.7	65.1	.4	64.8	.1
SEPT.	54.5	56.9	2.4	56.0	1.5
OCT.	43.2	37.7	-5.5	42.2	-1.0
NOV.	29.0	26.3	-2.7	27.5	-1.5
DEC.	16.3	19.3	3.0	20.6	4.3
MEAN	40.1	40.3	.2	38.7	-1.4



Surficial geology for Michigan from Farrand and Bell, 1982, 1:500,000.
Surficial geology for Wisconsin from Attig, 1985, 1:100,000.

Figure 5. Glacial geology of the Lac Vieux Desert watershed and surrounding area, Michigan and Wisconsin.

reported as an unqualified numerical value. Censored data are reported as less than a particular reporting level; for example, less than (<)0.12 mg/L. Censored data result from the analyte either not being present or, if seemingly present, an inability to conclusively identify it. Estimated data are reported as qualified numerical values with an "E" before the number; for example, E.057. Estimated values can be less than, at, or greater than the analytical reporting level. An estimated value less than the reporting level means that the analyte can be identified and measured, but with less than 99-percent confidence that it is present. Estimated values at or above the analytical reporting level can result from a poor performance record of the analyte with the analytical method, matrix interference, or small sample volume.

Reporting levels used by the USGS NWQL include minimum reporting level (MRL), method detection limit (MDL), long-term method detection limit (LT-MDL), and laboratory reporting level (LRL). The MRL is the lowest measured concentration of an analyte that can be reliably reported. The MDL is the minimum concentration that can be measured and reported with a 99-percent confidence that the analyte is present. The LT-MDL is derived from the standard deviation of a minimum of 24 MDL spike samples over an extended period. The LRL is generally equal to twice the LT-MDL. The probability of reporting an analyte as a nondetection when it is present is less than 1 percent at the LRL. The LRL is used when NWQL determines that an MRL is no longer appropriate to a specific analyte or analytical method. Concentrations measured between the LRL and LT-MDL are reported as estimated concentrations.

Streamflow and Lake-Stage Measurement

Tributary stream inflow, Wisconsin River outflow, and LVD stage were monitored during this study. In 2002, a real-time streamflow-gaging station was established at the LVD outlet with instrumentation independently recording lake stage and Wisconsin River stage. Routine streamflow measurements were made at the Wisconsin River outlet and discrete streamflow measurements were made from 2002 through 2004 at the five major streams tributary to LVD.

Surface water enters LVD through these tributary streams and from other portions of the watershed as overland flow or through unmapped small streams. Discrete streamflow (discharge) measurements of the five tributaries were made during summer base-flow conditions. Standard USGS techniques were used to estimate streamflow (Carter and Davidian, 1968;

Rantz, 1982), typically with a current meter and wading rod. Streamflow measurements at the tributaries to LVD were often difficult to obtain, and in many instances, little or no flow was observed. Some of the measurements are rated “poor”. Discharge measurement ratings are intended to convey the accuracy of a given measurement. A number of factors are considered when rating a discharge measurement, including but not limited to, characteristics of the measurement cross section, spacing and number of observation verticals, distribution of flow in the cross section, variability of velocity during the timed interval, and extent of change in stream elevation during the discharge measurement. Streamflow estimates were made when flow conditions precluded the use of a current meter.

Water Quality of Lac Vieux Desert Watershed

Factors that affect water quality of a lake are complex and interrelated. Geological and geomorphic characteristics of the watershed, as well as hydrological and biological components of the ecosystem, all affect the water chemistry of a lake or reservoir. LVD has a large surface area and is relatively shallow compared to many other lakes of its size. For most lakes in the northern United States, there is an appreciable difference in field water-quality parameters and concentrations of chemical constituents between seasons, and LVD is no exception.

There are five known tributaries to the lake that drain geomorphically diverse watersheds. Water from each of the tributaries enters the lake through wetland areas that can profoundly affect the water chemistry. Environmental staff from the LVD Band have been measuring water temperature, dissolved oxygen, specific conductance, and pH and collecting water-quality samples of three major tributaries to LVD for 4 years (Marsh Bay, Misery, and Lobischer Creeks) (fig. 1). As of September 2005, the LVD Band had not yet established a comprehensive water-quality standard, or released the data from their study of the tributaries.

The primary purpose of measuring field water-quality parameters and collecting water-quality samples at LVD during this study was to establish a baseline surface-water quality database. Future lake monitoring, data collection, and interpretation could be enhanced with the database established in this study.

Effect of Stratification and Turnover on Water Quality of Lac Vieux Desert

The following discussion of stratification and turnover in LVD serves to highlight issues pertinent to the present study. The reader is directed to Hutchinson (1957), Wetzel (2001), or other limnology texts for a more detailed discussion of the terminology, concepts, and field data related to this discussion.

Lakes can be classified based on their stratification and circulation patterns. During this study, LVD was observed to be polymictic (stratifying irregularly during the year, or not all), as is typical of shallower lakes in the region. In temperate climates, a polymictic lake is ice-covered during part of the year. During the ice-free period, water circulates freely in a polymictic lake without stratification, except for brief periods, perhaps as few as 3-5 days at a time (Dale Robertson, U.S. Geological Survey, oral commun., 2005).

Although LVD is probably unstratified through much of the year, a brief discussion of the physics of stratification is included for clarification. Vertical circulation of the water column in a lake is primarily affected by water temperature, wave action, and the lake depth. Water in the liquid state is most dense at 4°C and changes density with temperature. In dimictic lakes (those that actively stratify in ice-free periods), after ice out and as water begins to heat, the coolest water in the lake sinks to the bottom, forcing warmer (and less dense) water to rise to the surface. As this process occurs, the water column stratifies into three distinct layers described below. As little as a few degrees difference from the surface to the bottom of the water column affects the capacity of the entire water column to circulate and further accelerates stratification (Wetzel, 2001, p. 74) . In the fall, the warmer upper parts of a stratified water column cool as air temperatures decline. Eventually, the upper part of the water column cools below the temperature of underlying water and the cooler near-surface waters sink, causing vertical circulation and loss of stratification. This process is termed fall turnover. As temperatures cool to 0°C, ice forms on the lake surface.

The water column of a stratified lake can be divided into three distinct layers: the epilimnion, which is the upper layer of relatively warm (compared to waters below), circulating water; the metalimnion, which is the middle layer with a steep thermal gradient from warm on the top to cold at the base; and the hypolimnion, which is the lowermost layer that typically maintains the approximate temperature from initial stratification. Water temperature in the hypolimnion is most stable in deep lakes and remains stable throughout the stratified period in dimictic lakes. The thermocline is the plane of maximum rate of decrease in temperatures with respect to depth. The metalimnion is also often referred to as the thermocline.

In the two areas of LVD that were stratified during this study (sites 3A and 5A) (fig. 6), water temperature and dissolved oxygen decreased with depth (figs. 7-9). Water temperatures at sites 3A and 5A were 5 to 7°C cooler at the deepest sampling points than at the surface (figs. 7 and 8). At site 5A, dissolved oxygen concentration was over 8 mg/L at the surface and nearly zero at the deepest sampling depth (about 39 ft) (fig. 9). Specific conductance also varied because of the release of dissolved materials, including iron, manganese, and phosphorus. Specific conductance measured at site 5A in August 2004 was 78 μS/cm near the surface and 114 μS/cm near the bottom. Obviously, if ground water is discharged into the hypoliminion, that discharge can also profoundly affect water chemistry, including the field water-quality parameters.

Non scientific literature directed primarily at sportsmen

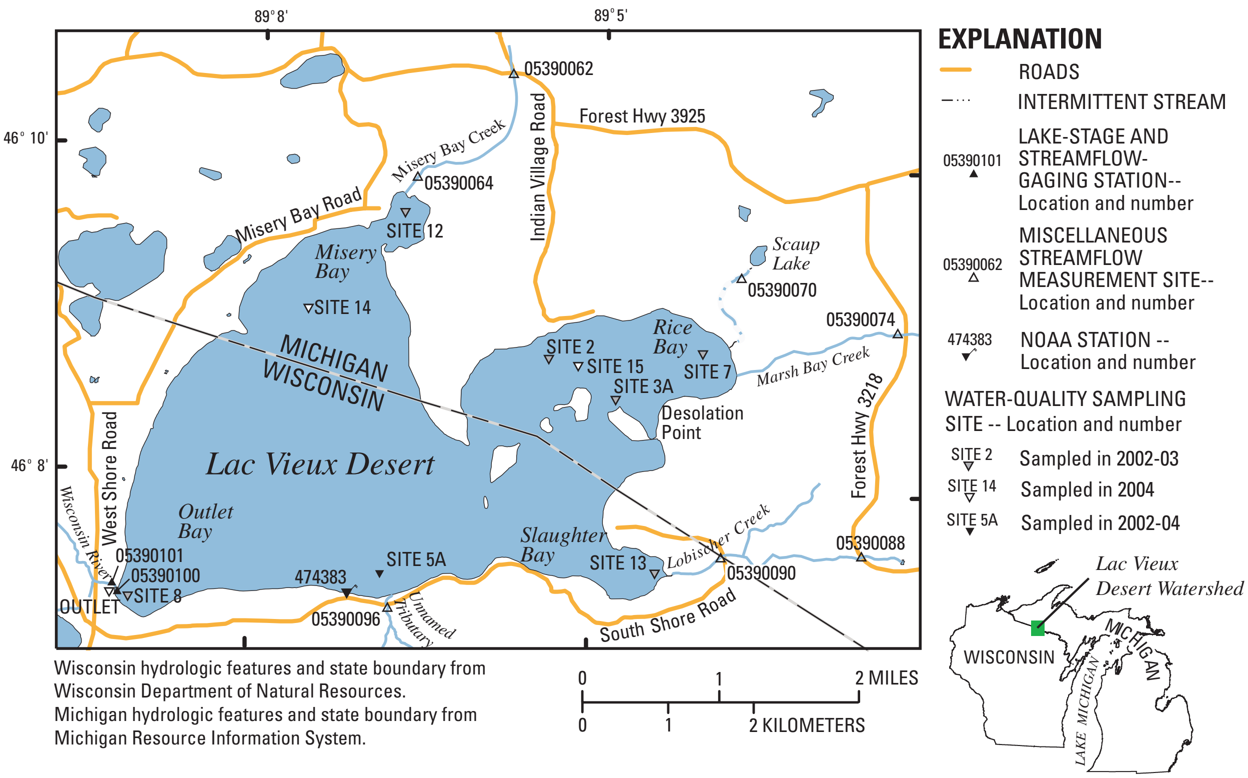


Figure 6. Identification number and location of lake-stage and streamflow-gaging stations, miscellaneous streamflow measurement sites, and water-quality sampling sites in and around Lac Vieux Desert, Michigan and Wisconsin.

(Fishing Hot Spots, 1992) and popular opinion of various local residents and fishing guides interviewed during this study indicated that LVD does not stratify during the summer. However, results from this study indicated that deeper parts of the lake can stratify, although not predictably, and probably not for extended periods of time (Dale Robertson, U.S. Geological Survey, oral commun., 2005). Water temperature in the hypolimnion is less stable in shallower lakes (Wetzel, 2001) such as LVD. During the 3 years of summer sampling at LVD, site 3A was not stratified in 2002, but was in 2003, and site 5A, which was sampled twice each year of the study, was stratified only once, in 2004. Weather, in particular the wind, is probably critical in determining whether LVD stratifies.

Water Clarity

Water clarity can be reduced naturally by suspended sediments, organics, free-floating algae, and zooplankton. Water clarity also can be affected by anthropogenic (human) activities, including watercraft use, which can stir up fine-grained lake-bed sediments and increase nearshore erosion. Secchi disk readings at LVD ranged from 2.0 to 7.0 ft during this study. The shallowest Secchi disk readings were measured in September 2003, when lake clarity was reduced appreciably by a pervasive algal bloom, which colored the entire lake grey-green.

Nutrients and the Trophic State of Lac Vieux Desert

One indicator of the water quality of a lake is its biological productivity, or trophic state. Four terms are used to describe the trophic state of lakes: “oligotrophic” lakes are those that are least productive; “mesotrophic” lakes are moderately productive; “eutrophic” lakes are productive; and “hypereutrophic” lakes have excessive productivity. Naturally occurring eutrophic and hypereutrophic lakes are known in North America, but, generally, the trophic status of lakes can be measured temporally (over a period of time) to determine anthropogenic and natural effect on water quality. A productive lake can be desirable for fish and wildlife populations, but excessive plant and algal growth can deplete oxygen and the lake can become hypereutrophic and would then be considered highly impaired. Above-normal nutrient enrichment can cause excessive productivity in a lake. Nitrogen and phosphorus are nutrients likely to affect productivity, primarily because they can theoretically generate 71 and 500 times their weight in algal matter, respectively. Absence of either nitrogen or phosphorus can impair productivity, but experimental studies in the Canadian Shield area of northwestern Ontario found that phosphorus was typically the limiting factor in productivity in northern lakes (Wetzel, 2001).

Nutrients above the natural "baseline" level most commonly enter lakes from septic systems or sewers, and agricultural and domestic application of fertilizers. Hem (1985) notes that sewage effluent is the largest single source of phosphorus in natural waters. Lakeside homeowners at LVD have improved many of the septic-sewage systems in the past 30 years (John Caskey, Wisconsin Valley Improvement Company dam operator and lakeside resident, oral commun., 2002). Septic systems have been installed where effluent may have previously drained directly to the lake. In addition, septic systems have been reconstructed with large-capacity tanks and improved drain fields. However, year-round residency at many lakes in the northern United States, including LVD, has substantially increased during the same 30-year period. The resultant input to septic systems occurs year-round rather than seasonally. This year-round input is also likely to contribute increased loads of constituents such as phosphorus and boron, which are, or have been in the recent past, used in detergents for washing machines and dishwashers.

In 1996, Barton and Grannemann (1998) sampled for nutrients at 3 sites in March, and 10 sites in October as part of an investigation of the water quality of LVD and unconsolidated aquifers north of the lake. Laboratory analyses showed total phosphorus concentrations ranged from 0.01 to 0.03 mg/L at all LVD sites except the March sample at site 3, which had a concentration of 0.17 mg/L. Field notes from the March sampling, which was done through the ice, indicated that water at site 3 was exceptionally cloudy and smelled strongly of decaying organic matter. In comparison, total phosphorus concentrations ranged from 0.01 to 0.064 mg/L during 2002-04. Dissolved nitrite plus nitrate nitrogen concentrations ranged from at detection limit levels to 0.052 mg/L during the same period. When lakes with abundant plants and algae, such as in LVD, have plant die-offs, the material sinks and decays on the lake bottom, releasing stored nutrients. The net effect of additional nutrients entering the lake may be summertime algal blooms similar to those observed at LVD during September 2003. Overabundance of nutrients in LVD, particularly nitrogen and phosphorus, could result in considerable degradation in lake-water quality. The pervasive bloom observed in September 2003 that discolored the lake and resulted in reduced transparency may have been caused by diatoms (Bacillariophyceae), which are a silica-rich phytoplankton that are the most prevalent group of algae (Wetzel, 2001). Silica in water samples collected during the September 2003 bloom was at concentrations from two to three times greater than during any other sampling. Wetzel (2001) noted that silica levels fluctuate throughout the year in most lakes in North America that he studied.

Chlorophyll-*a* is a photosynthetic pigment found in algae (Wetzel, 2001). Highest concentrations of chlorophyll-*a* are typically observed in mid- to late-summer when lake temperature is near maximum. As noted previously, algae is an essential component of a biologically productive lake, but excessive amounts often result in water-quality degradation and are an indicator of eutrophication, and in extreme cases, hypereutrophication. For purposes of comparison with the MDEQ Inland Lakes Study (Minnerick, 2004; R.J. Minnerick, U.S. Geological Survey, oral commun., 2002), chlorophyll-*a* was collected in LVD during this study from throughout the photic zone, which was considered to be twice the depth at which the Secchi disk was visible from the water surface. Chlorophyll-*a* concentrations ranged from 1.5 to 10.7 µg/L.

Nutrient concentration and its effects on the biological productivity of LVD were evaluated using Carlson's Trophic-State Index (TSI) (Carlson, 1977). The TSI can be computed using three different variables: Secchi disk readings; chlorophyll-*a* concentrations, and total phosphorus concentration, which was collected from the epilimnion. Carlson's TSI was developed for lakes with few rooted plants and little algal turbidity. Therefore, thresholds defined by Carlson for the trophic states require some modification when applied to lakes with abundant vegetation like LVD. TSI values were not averaged and each indicator was evaluated independently. Sampling depth, Secchi disk transparency, and concentrations of phosphorus and chlorophyll-*a* at five sampling sites at LVD are summarized in table 4.

Equations used to compute the TSI are

$$TSI_{(\text{Secchi disk})} = 60\text{-}14.41 * \ln(\text{Secchi disk reading, in m}), \quad (1)$$

$$TSI_{(\text{Total phosphorus})} = 14.42 * \ln(\text{Total phosphorus concentration, in } \mu g/L) + 4.15, \quad (2)$$

$$TSI_{(\text{Chlorophyll})} = 9.81 * \ln(\text{Chlorophyll-}a \text{ concentration, in } \mu g/L) + 30.6. \quad (3)$$

Minimum, maximum, mean, and median TSI calculations for LVD are summarized in table 5 using Secchi disk transparency, and concentrations of total phosphorus, and chlorophyll-*a* listed in table 4. In 1982, MDNR (currently MDEQ) altered Carlson's trophic state classifications to account for regional characteristics typical for lakes in the northern Midwest (table 6). When median Carlson's TSI calculations and Secchi disk transparency readings, phosphorus and chlorophyll-*a* concentrations, and analytical results are input into the MDEQ classification system, LVD is considered eutrophic.

A comparison of the data from previous studies with those collected during the current study indicates little change with respect to TSI from 1973 through 2004, although data are sparse between 1981 and 2002. Carlson's TSI calculations using data collected by WVIC, MDNR/MDEQ, and USGS from 1973 through 2004 are summarized in table 7. Samples collected by WVIC from 1973 through 1983 were not analyzed for chlorophyll-*a*, but Secchi disk transparency and total phosphorus concentrations were similar to data collected from 1981 through 2004.

Field Water-Quality Parameters, Major Ions, Solids, Nutrients, and Hardness

A summary of USGS National Water-Quality Laboratory (NWQL) lab codes and schedules used for this study is provided in table 8 and field water-quality parameters, major ions, solids, nutrients, and hardness of water samples collected at LVD are summarized in appendix A.

The pH of water in LVD ranged from 6.5 to 9.5, and specific conductance ranged from 62 to 114 µs/cm. The range of pH and specific-conductance values was indicative of multiple sources of input into the lake, and seasonal- and depth-related variations in water chemistry. Chloride concentration was less than 1.5 mg/L, indicating little effect from septic-tank or road-salt input. Results indicate that the water can be classified as soft (Hem, 1985), with hardness concentrations reported as calcium carbonate ranging from 29 to 49 mg/L. Concentrations of calcium, magnesium, chloride, and other dissolved solids (residue on evaporation) ranged from 47 to 77 mg/L. Alkalinity, which is a measure of the capacity to react with and to neutralize acid (Hem, 1985), enables prediction of how easily acid rain can affect water quality of a specific water body. Alkalinity in most natural waters is produced by dissolved carbon dioxide species (carbonate and bicarbonate) and the data from LVD are expressed in equivalent calcium carbonate units. Alkalinity of LVD ranged from 27 to 38 mg/L. Some states have established guidelines for lakes that are considered acid-impaired, but Michigan does not currently (2005) have a standard (Ralph Bednarz, Michigan Department of Environmental Quality, oral commun., 2005). However, LVD is considered non-sensitive to acid rain using Wisconsin's alkalinity standards, which are summarized in table 9.

Ammonia

In a sample collected 1.0 m above the bottom at site 5A in August 2004, ammonia concentration was an order of magnitude greater than in any other sample collected during the study. Dissolved-oxygen concentration measured at the same time was low (0.37 mg/L) indicating typical anoxic conditions near the bottom when LVD is stratified. When appreciable amounts of organic materials reach the hypolimnion of stratified lakes, ammonia can accumulate, particularly as the water becomes anoxic. Under anaerobic conditions, bacterial nitrification of ammonia ceases and ammonia concentration increases. Additionally, a large percentage of ammonia is adsorbed on sediment particles in the presence of oxygenated water. When anoxic or near-anoxic conditions prevail, as is typical in a hypolimnion, the adsorptive capacity of the sediments is decreased and a marked release of ammonia results (Wetzel, 2001).

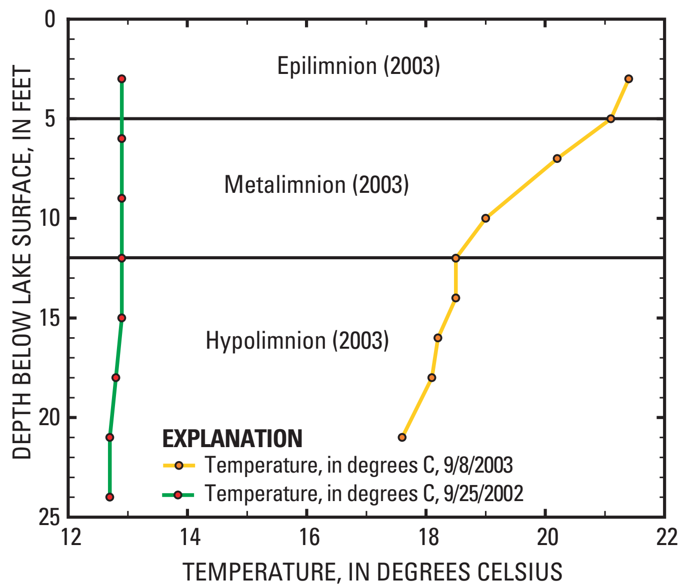


Figure 7. Thermal stratification of Lac Vieux Desert, Michigan, at sampling site 3A, September 2002 and September 2003.

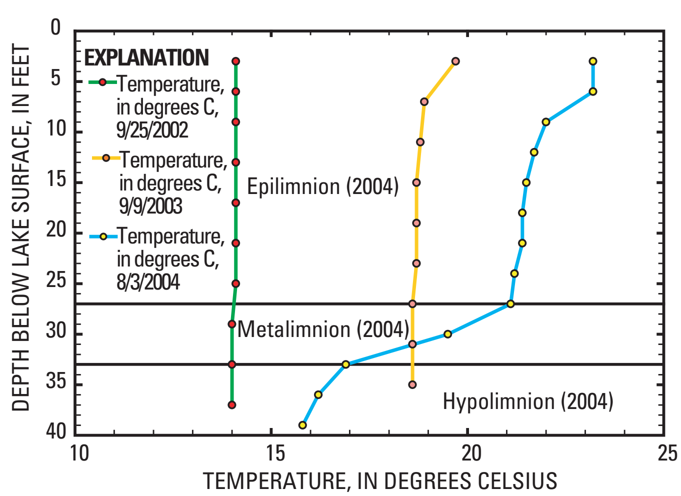


Figure 8. Thermal stratification of Lac Vieux Desert, Wisconsin, at sampling site 5A, September 2002, September 2003, and August 2004.

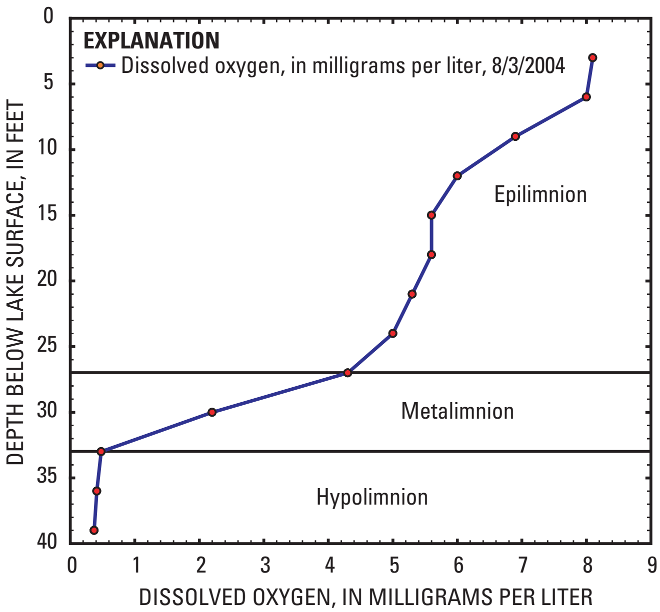


Figure 9. Dissolved-oxygen concentration and depth, Lac Vieux Desert, Wisconsin, at sampling site 5A, August 3, 2004.

Mercury

Organic complexes, such as methyl mercury, can be produced in oxygen-poor environments including wetlands (Hem, 1985) similar to those adjacent to much of LVD. The complexes, which are concentrated in the aquatic food chain and include fish, can be produced by methane-generating bacteria in contact with elemental mercury (Wood and others, 1968). Concentrations of total and methyl mercury at LVD (table 10) were typical of surface-water bodies throughout the Midwest that are relatively unaffected by industrial deposition (J.F. DeWild, U.S. Geological Survey (Wisconsin Water Science Center Mercury Laboratory), written commun., 2004).

Invasive Species

Eurasian Milfoil is a particularly aggressive invasive aquatic plant that grows throughout the northern United States and frequently establishes itself at the expense of native plant species. WDNR did not include LVD in a list of lakes affected by Eurasian Milfoil (Wisconsin Department of Natural Resources, 2003a) and they also note that Eurasian Milfoil is easily mistaken for Northern Water Milfoil or Coontail. In August 2003, USGS personnel completing a cursory evaluation of macrophytes for MDEQ noted Eurasian Milfoil growing along the northern and western shores of LVD.

From 2002-04, USGS personnel did not detect zebra mussels, which are found in other lakes in northern Wisconsin (Wisconsin Department of Natural Resources, 2003b) and the Upper Peninsula of Michigan. Zebra mussels can profoundly affect lakes in a number of ways, including displacing native mussels and increasing water clarity, with resultant algal blooms that result in oxygen deprivation. At the end of data collection for this study (2004), the WDNR was monitoring LVD, Trout Lake, and the Wisconsin River in Vilas County (fig. 2) for the presence of zebra mussels. Rusty crayfish and the fish parasite Heterosporis are both found in LVD, and spiny water fleas have been found in nearby Lake Gogebic (Tom Pietila, Lac Vieux Desert Band, oral commun., 2005).

Hydrology of Lac Vieux Desert Watershed

Lake stage and outflow at LVD are affected by variation in the water balance and by regulation of the dam at the outlet. Inputs to the water balance for LVD include runoff from five small tributary streams, direct precipitation falling on the lake surface, and ground-water seepage into the lake. Conversely, water leaves LVD through outflow to the Wisconsin River and by evaporation. Seepage outflow is typical of many northern lakes as well, but was not measured at LVD for this study. Seepage outflow was not considered to be significant because of the large surface area of the lake and resultant large evaporation rates, and relative ease with which water can exit the lake through the outlet.

Tributary Streamflow

Tributary stream inflow to LVD was monitored during this study. Discrete streamflow (discharge) measurements of the five tributaries were made during summer base-flow periods and are summarized in table 11.

Misery Creek

The Misery Creek drainage basin includes an area of about 4.7 mi^2 north of LVD, and empties into the lake at Misery Bay (figs. 1 and 6). Misery Creek flows through a 2 ft culvert under Gogebic County Road 210 (Indian Village Road, USGS site 05390062) and was only a few inches deep when it was inspected from 2002 through 2004. A downstream site, located about 0.15 mi upstream from the mouth (USGS site 05390064; figs. 6 and 10) was accessed by canoe in 2003 and 2004. The area between the two sites is poorly accessible because it is almost entirely wetlands. Streamflow was estimated at site 05390062 during an inspection in September 2002, after it was determined that a current-meter measurement could not be made because of low velocity and shallow depth. In September 2003, a streamflow measurement was made at site 05390064. This site was accessed again in August 2004, but no quantifiable flow was present at that time, and instead, another estimate of streamflow was made at site 05390062. Average runoff from Misery Creek is estimated to be 1.4 ft^3/s or about 0.30 $ft^3/s/mi^2$ of drainage area.

Scaup Lake Outlet

Scaup Lake outlet drains an area of approximately 1.3 mi^2 northeast of LVD, discharging into Rice Bay in a large marshy area about 0.2 mi north of Marsh Bay Creek inlet (figs. 1 and 6). The entire length of the stream channel is shown as intermittent and swampy on the USGS Imp Lake, MI 7.5-minute quadrangle map. Scaup Lake outlet crosses an old remote logging road approximately 0.75 mi upstream of Rice Bay, but the streamflow is not channelized at that location (USGS site 05390070; fig. 6). An inspection of the site was made on June 20, 2002. At that time, no quantifiable streamflow was noted, although approximately 50 ft of the logging road was saturated or submerged. It is likely that flows were confined to a channel prior to the construction of the logging road and the road is now impeding flow. However, no predecessor channels or culverts were located during the June 2002 inspection. It is also possible, if not likely, that outflow from Scaup Lake through the outlet occurs seasonally and intermittently, primarily as a result of snowmelt and runoff. Access to the stream is problematic because of overgrowth on the logging road and swampy conditions. No streamflow measurements were made at the site given the lack of visible flow and poor access to suitable gaging sites either upstream or downstream of the logging road crossing. Runoff from Scaup Lake outlet is assumed negligible for purposes of this study.

Marsh Bay Creek

The Marsh Bay Creek drainage basin includes an area of about 4.8 mi^2 east of LVD, and the creek empties into LVD at Rice Bay about, 0.2 mi south of the Scaup Lake outlet (figs. 1 and 6). Streamflow in Marsh Bay Creek was measured in 2002 at the downstream side of a 6-ft diameter culvert under Forest Highway 3218 (USGS site 05390074, figs. 6 and 11), approximately 1.35 mi upstream of Rice Bay. In 2003, a beaver dam below the culvert caused stagnant flow conditions at the culvert. Another streamflow measuring section was found about 300 ft downstream from the initial site and was used for streamflow measurements made in 2003 and 2004. Swampy conditions are present the entire length of Marsh Bay Creek. A photograph taken in 2004 about 0.75 mi downstream from site 05390074 (fig. 12) shows swampy conditions that are typical of most of the downstream parts of all streams tributary to LVD. Average runoff from Marsh Bay Creek is estimated to be 0.56 ft^3/s or about 0.12 $ft^3/s/mi^2$ of drainage area.

Lobischer Creek

Lobischer Creek originates approximately 2 mi east of LVD, includes a drainage area of about 5.0 mi^2, and empties into the lake at Slaughter Bay (figs. 1 and 6). Lobischer Creek flows through a culvert under a private road approximately 0.45 mi upstream of Slaughter Bay. All but one streamflow measurement was made at the culvert (USGS site 05390090; fig. 6). An upstream site (USGS site 05390088, figs. 6 and 13) was measured once in 2004. Backwater conditions were present at the downstream site at some lake stages, which occasionally prevented flow measurement. Average runoff from Lobischer Creek is estimated to be 1.64 ft^3/s or about 0.32 $ft^3/s/mi^2$ of drainage area.

Unnamed Tributary on South Side of Lac Vieux Desert

An unnamed tributary stream on the south side of LVD originates at or near Potfish and Sugar Maple Lakes (fig. 1) at altitudes of 1,713 ft and 1,722 ft above NGVD 29, respectively, and drains approximately 2.9 mi^2 before emptying into LVD on the southern shore (figs. 1 and 6). The unnamed tributary drops approximately 30 ft in elevation in the first mile downstream of Potfish Lake, by far the steepest gradient of any of the five tributaries. Approximately 0.3 mi upstream from the mouth, the gradient flattens and the stream enters a wetland area, which is visible from South Shore Drive. Downstream of the wetland area, the unnamed tributary is narrow and channelized, and flows through a culvert under South Shore Drive (fig. 6), about 0.10 mi upstream of the mouth. Streamflow measurements were made at the road crossing (USGS site 05390096, figs. 6 and 14). Average runoff from the unnamed tributary on the south side of the lake is estimated to be 0.84 ft^3/s or about 0.29 $ft^3/s/mi^2$ of drainage area.

Factors Affecting Lake Stage

LVD lake stage fluctuations are caused by natural factors and anthropogenic influences that affect the flow of water into and out of the lake. Lake stage is also affected by the physical dimensions of the lake system, particularly the outflow channel. The primary natural factors affecting lake stage are overlake precipitation, runoff from the drainage basin, groundwater inflow and outflow, evaporation from the lake surface, and flow through the outlet channel. LVD stage is also affected by the lake-storage capacity. Anthropogenic influence on the LVD lake stage is primarily through regulation of outflow to the Wisconsin River.

Factors affecting LVD lake stage can be described using a water-balance approach. A water balance is an accounting of all water entering and leaving a given body of water, for a given period of time. Mathematically, this balance can be expressed as "*inflow equals outflow plus change in storage.*"

Table 4. Sampling depth, transparency, and concentrations of total phosphorus and chlorophyll-a in Lac Vieux Desert, Michigan and Wisconsin.

[ft, feet; m, meters; P, phosphorus; µg/L, micrograms per liter; --, phosphorus data collected but sampling depth exceeds the near-surface threshold for Trophic Status Index (TSI) analysis; chlorophyll samples are composites collected through the water column from the surface to two times the depth of the photic zone; VOB, visible on lake bottom, not used in TSI calculations; E, estimated value from laboratory, not used in calculations; site locations shown in figure 6]

	Site 3A (4608330890449)				Site 5A (4607260890650)						Site 14 (460903089073)		Site 15 (4608460890510)		Lac Vieux Desert at outlet (4607170890909)	
Property or constituent	5/15/02	9/25/02	5/14/03	9/8/03	5/15/02	9/25/02	5/15/03	9/9/03	5/11/04	8/3/04	5/12/04	8/2/04	5/11/04	8/3/04	5/12/04	8/2/04
Transparency (Secchi disk) (ft)	4.5	5.3	4.5	4.0	4.4	4.4	4.5	4.0	6.5	7.0	7.0	5.7	7.0	VOB	VOB	VOB
Transparency (Secchi disk) (m)	1.4	1.6	1.4	1.2	1.3	1.3	1.4	1.2	2.0	2.1	2.1	17	2.1	VOB	VOB	VOB
Phosphorus (unfiltered, in µg/L as P)	--	--	--	--	--	--	--	--	22	31	18	26	33	22	33	32
Chlorophyll-a (µg/L)	1.5	4.4	6.5	3.7	10.7	8.9	5.9	5.9	8.2	E.80	7.2	E2.5	5.4	E1.7	9.4	E29

Median values are: Secchi disk transparency 4.5 ft, total phosphorus 31 µg/L, and chlorophyll-a 6.2 µg/L.

Table 5. Carlson's Trophic-State Index calculations for Secchi disk transparency, and concentrations of total phophorus and chlorophyll-a in Lac Vieux Desert, Michigan and Wisconsin.

Property or constituent	Minimum	Maximum	Mean	Median
Secchi disk transparency	49	57	52	53
Total phosphorous	46	55	51	51
Chlorophyll-a	35	54	48	49

[All values are dimensionless]

Table 6. Lake trophic states and classificiation ranges for Trophic-State Index, Secchi disk transparency, and concentrations of total phophorus and chlorophyll-a for Michigan (median values for Lac Vieux Desert, Michigan and Wisconsin are shown for classification purposes).

[Based on the report by Michigan Department of Natural Resources (1982) and modified by the State of Michigan to account for regional characteristics more typical of northern lakes. TSI, Carlson's Trophic-State Index; SDT, Secchi disk transparency; TP, total phosphorus concentration; ft, feet; µg/L, micrograms per liter; <, less than; >, greater than]

Lake trophic condition	Carlson's TSI (dimensionless)	SDT (ft)	TP (µg/L)	Chlorophyll-a (µg/L)
Oligotrophic	<38	>15	<10	<2.2
Mesotrophic	38-48	7.5-15	10-20	2.2-6
Eutrophic	49-61	3-7.4	20.1-50	6.1-22
Hypereutrophic	>61	<3	>50	>22
Lac VieuxDesert (median values)	51	4.5	31	6.2

The mathematical expression of the LVD water balance is described in equations 4-6 below.

$$Inflows = P + R + G_{in} , \quad (4)$$

$$Outflows = O_{WR} + E + G_{out} , \quad (5)$$

$$P + R + G_{in} = O_{WR} + E + G_{out} + \Delta S, \quad (6)$$

where P is precipitation falling directly on the lake,
R is runoff,
G_{in} is ground-water inflow,
O_{WR} is Wisconsin River outflow,
E is evaporation from the lake surface,
G_{out} is ground-water outflow, and
ΔS is change in storage of the lake.

Variation in the water balance of a lake can be quantified through evaluation of the net basin supply (NBS). As will be demonstrated below, this process makes it possible to assess how dam regulation at LVD affects the lake stage and Wisconsin River outflow. Simply stated, NBS is the net amount of water flowing into a lake during a given period of time. Conceptually, NBS must be balanced by outflow from a lake, or by a change in the amount of water stored in the lake, which is reflected in changes in lake stage. If NBS exceeds outflow from the lake, the lake stage rises. Conversely, if outflow from the lake exceeds NBS, the lake stage declines. If NBS equals outflow, the lake stage is stable. Mathematically, NBS can be expressed as

$$NBS = P + R + G_{net} - E, \quad (7)$$

$$NBS = O_{WR} + \Delta S, \quad (8)$$

where G_{net} is the net ground-water inflow, ΔS is change in storage.

Combination of equations 7 and 8 yields equation 9, as

$$P + R + G_{net} - E = NBS = O_{WR} + \Delta S. \quad (9)$$

NBS is balanced by outflow in the long term (tens of years). However, in the short term (from hours to 3-5 years), an imbalance between these components is common and is reflected in changes in lake stage. All of the components in equations 4-9 are variable over multiple time scales. This variability causes fluctuation of lake stage and outflow over multiple time scales. On a time scale of tens of years, or longer, changes can result from persistent low or high NBS possibly caused by climate change. On a shorter time scale of hours to a year, seasonal fluctuations in various hydrologic cycle components occur and cause variability in NBS. For example, NBS during spring and early summer is usually greater than at other times of the year, largely resulting from increased runoff from spring snowmelt. In a natural lake system, this phenomenon causes increased outflow and high lake stage in the spring and early summer. At LVD, seasonal fluctuations also result from regulation of outflow to the Wisconsin River to meet hydroelectric power-generation requirements at downstream dams under regulation by FERC (Wisconsin Valley Improvement Company, 2004).

Table 7. Carlson's Trophic-State Index (TSI) calculations for Secchi disk transparency, and concentrations of total phophorus and chlorophyll-a in Lac Vieux Desert, Michigan and Wisconsin, for samples collected by Wisconsin Valley Improvement Company (WVIC), Michigan Departments of Natural Resources and Environmental Quality (MDNR/MDEQ), and U.S. Geological Survey (USGS).

[All values are dimensionless; --, chlorophyll-*a* data not collected by WVIC during this period]

Year	Secchi disk transparency	Total phosphorus	Chlorophyll-*a*
1973-83 (WVIC)	52	56	--
2000-02 (WVIC)	50	50	54
1981 (MDNR)	46	52	35
1994 (MDEQ)	54	49	46
[1]2002-04 (USGS)	53	51	49

[1] Data from 2002-04 are median TSI values from the present study provided for comparison purposes. Appendix 1 includes complete listing of all TSI values.

Table 8. U.S. Geological Survey National Water-Quality Laboratory lab codes, schedules, and respective analytes used for sampling at Lac Vieux Desert, Michigan and Wisconsin, 2002-04.

[LC, lab code; SCH, schedule]

Year	Lab code or schedule	Analyte
2002-04	LC 165	Residue on evaporation (solids)
2002	LC 586	Chlorophyll-*a* (replaced by SCH 1508 after May 2002)
2002-04	SCH 865	Low-level nutrients
2002-03 (sites 3A and 5A only) 2004 (all sites)	SCH 1508	Chlorophyll-*a* (replaced LC586 after May 2002)
2004	LC 2110	Boron
2002-04	LC 2187	Turbidity
2004	LC 2333	Phosphorus
2002-03, except site 5A (2002-04)	SCH 2701	Major inorganics

Water-Balance Components

Inflows in the LVD water-balance calculation include runoff to the lake from the surrounding landscape, precipitation falling directly on the lake surface, and ground-water seepage into the lake. Outflows in the LVD water-balance calculation include evaporation from the surface of the lake, outflow to the Wisconsin River, and ground-water seepage from the lake. Ground-water seepage from LVD is considered negligible in comparison with evaporation and outflow to the Wisconsin River. Temporary changes in lake stage are accounted for in the water-balance calculation and are treated herein as a water-balance component.

Table 9. Sensitivity of lakes to acid rain; guidelines for Wisconsin (Wisconsin Department of Natural Resources, 2004).

[Alkalinity is in units of milligrams per liter as $CaCO^3$; >, greater than]

Sensitivity	Alkalinity
High	0-2
Moderate	>2-10
Low	>10-25
Nonsensitive	>25

Runoff

Runoff enters LVD either directly from the surrounding landscape as overland flow through small, unmapped tributary streams, or through five tributary streams (Misery Bay Creek, Scaup Lake outlet, Marsh Bay Creek, Lobischer Creek, and an unnamed tributary that flows into the lake along the south shore) (fig. 6). These five streams drain 18.7 mi^2 or 67 percent of the watershed (table 12). Parts of all of the tributary streams are mapped as intermittent drainages on USGS 7.5-minute quadrangle maps. Four of the five tributary streams originate in wetland areas or lakes that are 10 to 15 ft higher in elevation than Lac Vieux Desert. The unnamed tributary on the south shore originates in or near Potfish Lake, which has an elevation of 1,713 ft above NGVD 29, 33 ft higher than LVD (USGS, Phelps WI 7.5-minute quadrangle map).

Runoff varies seasonally in the study area. For this study, runoff was estimated in three periods: summer, winter, and snowmelt. Summer periods are defined as open-water, non-snowmelt periods. Winter periods are defined as ice-up to ice-out, not including snowmelt periods. Snowmelt periods are typically defined as from 6 weeks prior to ice-out through the end of June. Over the entire study period, runoff was estimated at 19.4 ft^3/s (0.56 $ft^3/s/mi^2$), or 50 percent of all water entering LVD (fig. 15, table 13).

Percentages and flows shown in figure 15 and table 13 are estimates. Differences in the sum of inputs, outputs, and change in storage results from uncertainties in estimates of the various components of the water balance. Uncertainties are relatively large on a monthly basis, but tend to balance out over longer time scales (years). The average imbalance between inputs, outputs, and change in storage in monthly estimates was ±9.6 ft^3/s, whereas the sum of imbalances over the 25-month study was equivalent to -0.2 ft^3/s/month. In comparison, average Wisconsin River flow during the same period was 28.0 ft^3/s.

For open-water, non-snowmelt months, total runoff to LVD was estimated to be 6.6 ft^3/s by extrapolating the ratio of runoff-to-area in gaged and ungaged areas of the LVD drainage basin. Streamflow (discharge) on the five tributaries was measured at six sites during open-water, non-snowmelt periods. To extrapolate runoff estimates to ungaged areas, streamflow measurements of each stream were averaged and defined as the average runoff from the gaged portion of each stream (table 14). The ratio of runoff-to-area from the gaged portion of stream was used to determine the runoff from ungaged portions of each stream. Runoff from the gaged and ungaged portions of each stream were summed and defined as the total runoff from each stream. Next, a weighted-average of runoff-to-area ratios was developed and used to determine runoff from all remaining land areas in the LVD drainage basin. Finally, runoff from all areas was added to determine total runoff to LVD.

Runoff during winter and snowmelt periods was estimated as a residual in water-balance calculations. Residual calculations incorporate errors from all other terms of the water balance, particularly short-term errors (days to months) from evaporation estimates. Consequently, longer-term (months to years) estimates are more reliable. Therefore, all estimates of runoff during winter and snowmelt periods were averaged to generate single values for these times of the year.

Table 10. Concentrations of total and methyl mercury in Lac Vieux Desert, Michigan and Wisconsin.

[All concentrations are in nanograms per liter; <, less than]

Site(fig. 6)	Sampling date	Total mercury-unfiltered	Methyl mercury-unfiltered
3A	9/8/2003	0.633	<0.04
Outlet	9/8/2003	.505	< .04

Precipitation

Long-term average annual precipitation for LVD is approximately 33.8 in (fig. 16). During the study period, precipitation was above normal in 2002 (41.1 in.), and below normal in 2003 (31.6 in.). Precipitation falling directly on the lake surface was estimated as the product of the surface area of LVD and the total amount of precipitation recorded at NOAA weather station 474383 (location shown on fig. 6). During 2002-03, precipitation averaged 17.7 ft^3/s, which is about 30 percent less than enters the lake through surface-water runoff. Precipitation is a net input to the water-balance computation, and constituted 35 percent of the water entering LVD (figs. 15 and 16, table 13).

Ground Water

Ground-water input was estimated as a residual in water-balance computations during open-water, non-runoff months. Ground-water input during these periods totaled approximately 6 ft^3/s. Equation 10, which was derived from equation 9, gives the mathematical computation of the ground-water component of the water balance.

$$G_{in} = O_{WR} + E + G_{out} + \Delta S - P + R \qquad (10)$$

Robertson and others (2003, p. 10) identified ground-water input to Muskellunge Lake, also located in Vilas County, as remarkably stable throughout the year. In the current study, it was assumed that ground-water input to LVD is stable throughout the year and that ground-water inflow rates calculated during open-water, non-runoff months are equivalent to other times of the year. Ground-water input to LVD was estimated to be a net input to the water balance, a constant 6.0 ft^3/s, or 15 percent of the water entering LVD (fig. 15, table 13).

Evaporation

Insufficient data were available to calculate evaporation from LVD. However, evaporation has been estimated in recent studies of five nearby lakes (Wentz and Rose, 1991; Robertson and Rose, 2000; Robertson and others, 2003; Lenters and others, 2005). Monthly estimates of lake evaporation for May through October from these studies agree relatively well with each other (table 15). In the current study, for May through October, the mean of the estimated evaporation rates for these five lakes was used to estimate the monthly evaporation rates for LVD. Evaporation for open-water portions of LVD during April and November are based on evaporation rates for May and October, respectively.

Water loss to the atmosphere during periods of ice cover results from sublimation and is appreciable in most lakes in the region. Wentz and Rose (1991, p. 7, 14) determined that sublimation accounted for approximately 4 to 6 percent of all water lost to the atmosphere at Clara and Vandercook Lakes in north-central Wisconsin. In this study, sublimation on LVD is assumed to account for approximately 5 percent of all water

Table 11. Flow measurements of streams tributary to Lac Vieux Desert, Michigan and Wisconsin.

[Site locations shown in figure 6; All values in cubic feet per second; --, indicates no measurement was made; p, proceeding the streamflow indicates the measurement was rated poor; e, preceding the value indicates that streamflow was estimated]

Date of measurement	Misery Creek (05390062)	Misery Creek (05390064)	Scaup Lake Outlet (05390070)	Marsh Bay Creek (05390074)	Lobischer Creek at Forest Hwy. 3218 (05390088)	Lobischer Creek (05390090)	Unnamed Tributary on South Shore (05390096)
06/20/02	--	--	[1]	0.97	--	--	--
09/10/02	e0.10	--	--	--	--	--	e1.0-1.5
09/08/03	--	1.97p	--	[2].18p	--	[3]0.22p	0.87
09/09/03	--	--	--	--	--	1.19	--
09/10/03	e.10	--	--	--	--	--	--
05/12/04	--	--	--	--	--	1.22	.95p
08/03/04	e<.05	[4]	--	[2].10p	0.34	1.69p	.69p

[1] Little or no apparent flow on this date. Water was covering at least 50 feet of road grade. No apparent channels downstream of road grade.

[2] Measurements made about 300 feet downstream of culvert at Forest Highway 3218 crossing used for initial measurement in 2002. Beaver dam made original site impossible to measure in 2003-04.

[3] Streamflow was affected by debris jam at upstream culvert. Debris removed and site was measured again on September 9, 2003.

[4] Streamflow could not be measured effectively with current meter on this day; flow rate extremely low, water over 1 foot deep.

Figure 10. Misery Creek, Gogebic County, Michigan, looking upstream near site 05390064, summer 2004. Photograph by Thomas Pietila, Lac Vieux Desert Band of Lake Superior Chippewa Indians.

lost to the atmosphere, a rate of 0.006 in/day during periods of ice cover. Evaporation for months of partial ice cover is based on evaporation for the number of open-water days and sublimation for the number of ice-covered days in each respective month. Evaporation is a net output to the water-balance computation, constituting 32 percent of water output from LVD (fig. 15, table 13).

Lac Vieux Desert Stage and Outflow

Periodic measurements of LVD lake stage have been made since 1908, and some daily measurements were made beginning in 1935. WVIC has recorded these data since at least 1950 and USGS data are available from September 1973 through September 1992, and from June 2002 through 2005 (station 05390100 (fig. 6) is currently scheduled to operate through at least September 2006). Outflow from LVD was compiled using streamflow data from the USGS streamflow-gaging station at the Wisconsin River outlet immediately downstream of the control structure (station 05390101) (fig. 6). The daily mean lake stage and daily mean streamflow of the Wisconsin River at the outlet for the study period is shown in figure 17 and a table of daily mean streamflow for the same period is provided in appendix B.

Outflow from July 1, 2002, through July 31, 2004, averaged 28 ft^3/s. As a net output to the LVD water balance, Wisconsin River outflow constituted about 68 percent of water leaving the LVD watershed during the study (fig. 15, table 13).

Effects of Outflow Regulation

Hydrology

The stage of LVD is affected by natural variation in the water balance and by regulation of the dam structure at the outlet. The clearest example of lake stage being affected by variation in the water balance is when stage rises in the spring largely in response to dramatically increased snowmelt-induced runoff. Water-balance variability occurs on time scales from hours to decades, but regulation of the outflow at the dam structure prevents lake stage from responding in a natural manner.

Dams affect rivers and lakes in three primary ways. First, the establishment of a dam may increase lake stage, which may inundate upland areas. Depending on the size and design of the dam, there can be a dramatic change in the temperature and water quality of outflow. In addition, regulation of a dam may alter the timing of outflow and fluctuation of lake stage. These effects may work independently or together and can dramatically alter the character of a lake or river.

The dam at LVD has had a minimal effect on LVD stage and Wisconsin River streamflow. The average lake stage of LVD has probably increased 1-2 ft, which does not appreciably affect Wisconsin River outflow. Depths at Outlet Bay (fig. 4) are relatively shallow, reaching a summer-time depth of approximately 5 ft or less and extending for at least 500 ft behind the dam (Fishing Hot Spots, 1992). This bathymetry indicates that the elevation of the original outlet could not have been dramatically lower than it is currently, even when compensating for sedimentation behind the dam. A second line of reasoning to support this conclusion is the comparison of shoreline location on current USGS topographic maps to an 1852 (pre-dam) survey map of LVD conducted by the State of Michigan. Although a

Figure 11. Marsh Bay Creek, Gogebic County, Michigan, looking upstream at U.S. Forest Highway 3218, summer 2004. Photograph by Thomas Pietila, Lac Vieux Desert Band of Lake Superior Chippewa Indians.

Figure 12. Marsh Bay Creek, Gogebic County, Michigan, looking upstream about 0.75-mile downstream of U.S. Forest Highway 3218, summer 2004. Photograph by Thomas Pietila, Lac Vieux Desert Band of Lake Superior Chippewa Indians.

century and a half and various dam structures separate the two generations of maps, each show a similar shoreline location and contour, supporting the conclusion that dam construction increased lake stage minimally.

Although the effect of outflow regulation on the daily variation of LVD lake stage is slight, the effect on daily variation of Wisconsin River streamflow is appreciable over time scales of days and months (fig. 17). Examples of abrupt, abnormal fluctuations in Wisconsin River streamflow resulting from regulation were observed in October and November 2002, and from March through June 2004. Prior to October 2002, hydrologic conditions were relatively stable, with the lake stage high and streamflow low. During the first 5 days of October 2002, lake stage and outflow rose in response to heavy precipitation and on October 7, outflow was increased to prevent the lake stage from increasing above an altitude of 1,681.53 ft (target maximum-lake stage mandated in the FERC license (Federal Energy Regulatory Commission, 1996)). Lake stage finally began to decline on October 11, and as it returned to its pre-October level, outflow was abruptly reduced in an effort to maintain a typical fall lake stage.

Variability of LVD lake stage and Wisconsin River streamflow is also affected on longer time scales of years and decades. To assess this effect, it is useful to estimate what the variability in lake stage and Wisconsin River outflow would be in the absence of dam regulation, and to compare that to what was observed during this study. First, a similar lake and river system is proposed as a model to simulate the pre-dam LVD-Wisconsin River system. Second, NBS estimates for LVD are used to estimate likely outflows and lake-stage changes in the absence of regulation.

Manistique Lake is in the eastern Upper Peninsula of Michigan (fig. 2) in a hydrologic setting similar to LVD. USGS personnel measured Manistique River outflow near the outlet from 1942 through 1950 and lake stage was monitored from 1942 through 1968. A small dam was built by MDNR to control Manistique Lake outflow in 1948 (Miller and Thompson, 1970). Dam construction altered natural outflow; therefore, evaluation of Manistique Lake and Manistique River dynamics is limited to the period from 1942 through 1947. In this comparison, bimonthly average flows and a 10-day rolling average of daily streamflow from 1942 through 1947 are used to represent average conditions during this period.

The relation between lake stage and outflow in the Manistique Lake-Manistique River system during 1942-47 is shown in figure 18. As with LVD, NBS at Manistique Lake typically

Figure 13. Lobischer Creek, Gogebic County, Michigan, looking upstream at U.S. Forest Highway 3218, summer 2004. Photograph by Thomas Pietila, Lac Vieux Desert Band of Lake Superior Chippewa Indians.

Figure 14. Unnamed tributarty on south side of Lac Vieux Desert, Vilas County, Wisconsin, looking upstream at South Shore Drive, May 2005. Photograph by Stephen Horton, U.S. Geological Survey.

rises dramatically in March and April as snowmelt and runoff occur. As inflow (runoff, precipitation, and ground-water inputs) to the lake increases, outflow (composed of Manistique River streamflow and evaporation) increases. However, outflow through the Manistique River (and the Wisconsin River below the outlet at LVD) is affected by stream geometry and other factors that retard outflow and result in a rising lake stage. As long as the imbalance between inflow and outflow is present, lake stage continues to rise. By late April, however, snowmelt typically ends and NBS declines (as inflow decreases, outflow decreases). Much of the water held back by rising lake stage during the spring is released throughout the summer, as outflow exceeds inflow. Inflow approximates outflow in September and October and results in a stable lake stage. Lake stage and outflow rise again in late fall as a result of stable or slightly increasing inflow and decreasing evaporation. During winter, outflow and inflow remain stable.

The relation between lake stage and outflow in the LVD-Wisconsin River watershed is shown in figure 19. NBS is included in the figure as an aid in tracking net inflow to the lake. At LVD, NBS is relatively stable throughout the winter, but lake stage and outflow decrease steadily during the period because of the regulated release of water that was in the lake the prior summer, as well as the lack of inflow. Lake stage and outflow become relatively stable just as spring snowmelt begins (note the abrupt rise in NBS in March). In an unregulated lake system, outflows would rise as NBS increases, but in the LVD system, outflows are artificially and appreciably reduced as the lake stage is raised in preparation for summer. The resultant change in lake stage and river outflow is much more abrupt than would occur in an unregulated lake system. When LVD stage approaches the target maximum, outflow is increased to prevent the lake from rising above the stage set in the FERC licensing agreement (Federal Energy Regulatory Commission, 1996; Wisconsin Valley Improvement Company, 2004; appendix C). By late May, NBS typically decreases and outflow is again reduced to store as much water as possible through the summer without raising lake stage above the target maximum or reducing Wisconsin River outflow below the FERC-mandated threshold of 5.5 ft^3/s. Beginning in October, outflow is increased to release stored water to augment late fall and early winter Wisconsin River flow for hydroelectric power production downstream.

Long-term variability of LVD lake stage is also affected by outflow regulation. Outflow is manipulated in an effort to maintain the stage between the target minimum and maximum. Additionally, stage is generally regulated the same way every year. This regulation prevents the stage from responding to long-term trends in climate, as would occur in a natural lake system. Typically, lake stage was held within a 2.17 ft range during the previous FERC licensing period (Federal Energy Regulatory Commission, 1996). However, the current FERC licensing agreement with WVIC calls for lake stage to be maintained within a 1.37 ft range from 2003 through 2012, between an altitude of 1,679.36 ft and 1,680.73 ft above NGVD 29 (U.S. Forest Service, 2004; Wisconsin Valley Improvement Company, 2004; appendix C). The intent of this regulation change is to reduce the degree to which maximum stage is higher than the natural stage prior to dam installation. The net result of the lower target-maximum stage is that outflow should increase in late spring and early summer because there is less need or legal ability to store water in the lake, and decrease during fall and winter because there is less water to release from storage.

In summary, seasonal regulation of LVD outflow results in an artificially high lake stage throughout the year, except for the period from late winter to very early spring, prior to snowmelt and runoff. Regulation of LVD outflow causes streamflow in the Wisconsin River to be artificially low during spring and summer and artificially high in fall and winter. Wisconsin River outflow is also more variable because of sudden and large adjustments to the outflow gates on the dam. The experimental lower target maximum lake stage for 2003 to 2012 will reduce the degree to which the stage is higher than would be present in the absence of regulation, and the net result should be increased outflow in late spring and early summer, and decreased outflow during fall and winter.

Ecology

Any deviation in LVD stage and outflow into the Wisconsin River has the potential to affect the ecology of the lake system. The nature, magnitude, and desirability (either positive or negative) of these ecological changes are complex.

One species of particular concern at LVD is wild rice (*Zizania sp.*). Wild rice is an herbaceous annual grass of cultural importance to the LVD Band (George Beck, Lac Vieux Desert Band, written commun., 2005) and most other Chippewa Bands in North America. Ancestors of the LVD Band settled near LVD and harvested rice growing in the lake for generations. Little data are available to quantify historical abundance of wild rice at LVD, but according to anecdotal accounts, it was once more abundant than what was observed in 2002. It is unclear if wild rice ever grew on the upper reaches of the Wisconsin River. According to a study done by Wisconsin Valley Improvement Company (1990a), wild rice grew in approximately 13 acres of Misery and Rice Bays, but has not been documented to grow in the Upper Wisconsin River in recent years.

Wild rice grows in shallow water in lakes and rivers over a wide portion of North America (Aiken and others, 1988). It provides excellent forage for migratory waterfowl and is widely harvested for the grain that it produces. Many factors can adversely affect wild rice production, including grazing, insect predation, fungal decimation, competition from other macrophytes, the quantity and quality of seed stock present, and variation in water depth during the growing season. Dams constructed by beavers (*Castor Canadensis*) can have a severe negative effect on the viability of rice populations by raising the stage of affected lakes and rivers. Rising stage because of regulation of manmade dams can have similar effects. On a long-term time scale (years to decades), occasional periods of unusually low stage, which might be typical of drought periods, may aid wild rice growth by reducing competition from other macrophytes.

Two reports by WVIC that evaluate the effect of LVD lake-stage regulation on wild rice growth in the lake note that modest areal distribution of rice at LVD may be attributable to lake-stage regime, lack of seed stock, or competition from other macrophytes (Wisconsin Valley Improvement Company 1990a, 1990b). Unpublished research (Peter Lee, Lakehead University, Thunder Bay, Ontario, written commun., 1997) indicates that lake-bed sediment at LVD may be too soft to support prolific wild rice because of its inability to protect and hold rice roots during high-energy wave action. Some evidence points to each of these factors. The history of lake-stage regulation appears to parallel the decline of wild rice in LVD, indicating that the altered hydrologic regime may also have affected wild rice development. Viable seed stock may be depleted in many parts of the lake by decades of crop failures. It may also be possible that competition from other macrophytes has increased because of long-term stability of regulated lake stage. The extent to which each of these independent factors has affected the decline of wild rice is unclear. It is possible that these factors collectively retard propagation of wild rice at LVD.

As part of a 10-year study on the effects of LVD lake stage on wild rice, in 2003 WVIC lowered the maximum stage about 0.8 ft and reduced the range of the stage to about 1.4 ft (U.S. Forest Service, 2004; Wisconsin Valley Improvement Company, 2004). The LVD Band (George Beck, Lac Vieux Desert Band, written commun., 2005), U.S. Department of Agriculture (U.S. Forest Service, 2004), and others hope that the combination of lower and more stable summer-time stage and the resultant decrease in water depth in the shallow bays will enhance rice propagation. The return of abundant wild rice would promote rice harvesting and increase migratory waterfowl abundance on the lake. Recent plantings of wild rice by the LVD Band have been successful, indicating that suitable habitat and hydrologic regime were present in 2004 and 2005. A summary of acreage with wild rice in Rice and Misery Bays is shown in table 16.

Aerial photographs of wild rice in Rice Bay (fig. 20) and Misery Bay (fig. 21) were taken in August 2005 by GLIFWC. The photographs show abundant wild rice growing in both bays, even though virtually little or no rice was present in Misery Bay as recently as 2002 (table 16).

Other Effects of Outflow Regulation

Outflow regulation has direct and indirect effects on recreation on LVD and the Wisconsin River. Watercraft access and the quality of fishing and hunting opportunities on LVD and possibly on the Wisconsin River would be affected. A high, stable lake stage during summer and fall typically aids fishing and waterfowl hunting and enhances boating and personal watercraft use on LVD by providing a predictable and convenient lake stage for public and private launches and docks. Conversely, regulated outflow from LVD in the summer may limit canoe and kayak access to the Wisconsin River downstream from the lake compared to what may have resulted with no regulation at the outlet. Indirectly, the effect of regulation on the ecology of the LVD-Wisconsin River system also affects recreational opportunities. Lake-stage regulation patterns likely affect the growth of aquatic plants, such as wild rice, which provide forage for waterfowl and support aquatic food webs. These patterns indirectly affect waterfowl hunting, fishing, and rice harvesting.

Regulation of LVD lake stage has reduced wintertime ice damage to the shoreline and flooding in the springtime. Like many lakes, LVD is susceptible to ice push, the move-

Table 12. Delineated areas of Lac Vieux Desert watershed, Michigan and Wisconsin.

[All areas delineated from U.S. Geological Survey 7.5 minute quadrangle maps; mi^2 , square miles]

	Lac Vieux Desert	With stream drainage	Without stream drainage	Total watershed
Area (mi^2)	6.6	18.7	9.1	34.4
Percentage of total watershed area	19.2	54.4	26.4	100

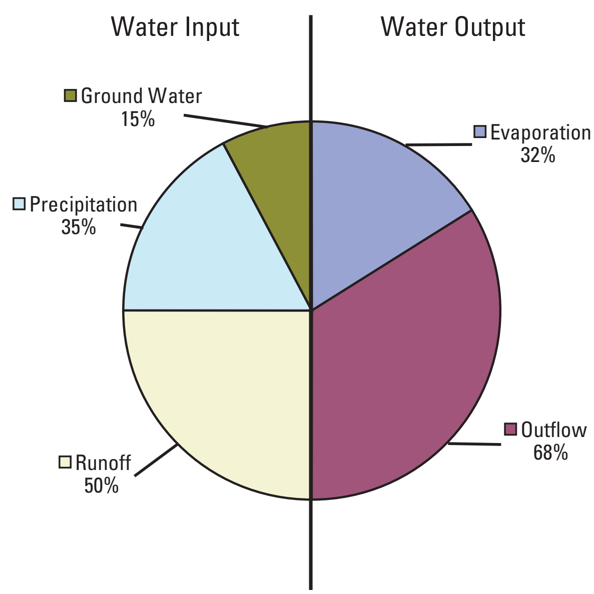


Figure 15. Estimated water input and output of Lac Vieux Desert, Michigan and Wisconsin, as a percentage of total water entering or leaving the lake. (%, percent)

Table 13. Magnitude of water-balance components and net basin supply to Lac Vieux Desert watershed, Michigan and Wisconsin, during the study period (July 2002 through July 2004).

[All values in cubic feet per second (ft3/s) unless otherwise noted, --, no applicable data]

	Water input			Water output		Change in storage	Net basin supply
	Runoff	Precipitation	Ground water	Evaporation	Outflow		
July-02	6.6	30.1	6.0	24.6	13.5	4.0	18.1
August-02	6.6	25.6	6.0	23.8	14.8	-13.7	14.4
September-02	6.6	29.6	6.0	18.8	15.0	8.8	23.4
October-02	6.6	31.7	6.0	14.8	51.1	-3.8	29.4
November-02	12.5	6.9	6.0	4.7	79.3	-41.4	20.7
December-02	14.3	3.8	6.0	1.0	63.9	-39.9	23.0
January-03	14.3	3.4	6.0	1.0	40.8	-22.9	22.6
February-03	14.3	5.3	6.0	1.0	31.6	-12.3	24.6
March-03	30.0	12.2	6.0	1.0	18.8	20.3	47.1
April-03	41.3	21.2	6.0	18.6	10.0	49.6	49.8
May-03	41.3	32.4	6.0	22.1	41.1	13.9	57.5
June-03	41.3	11.4	6.0	23.8	22.6	-18.9	34.9
July-03	6.6	18.7	6.0	24.6	12.5	-6.8	6.7
August-03	6.6	19.8	6.0	23.8	11.9	-13.1	8.6
September-03	6.6	21.2	6.0	18.8	9.8	-2.3	15.0
October-03	6.6	14.3	6.0	14.8	13.7	-0.8	12.1
November-03	12.5	16.5	6.0	4.7	30.8	-7.5	30.2
December-03	14.3	8.2	6.0	1.0	41.1	-19.6	27.5
January-04	14.3	1.4	6.0	1.0	31.2	-12.3	20.6
February-04	14.3	2.7	6.0	1.0	30.0	-4.6	21.9
March-04	35.2	3.9	6.0	1.0	29.1	15.7	44.0
April-04	41.3	5.6	6.0	14.4	14.0	75.8	38.4
May-04	41.3	3.9	6.0	22.1	39.9	-4.2	29.0
June-04	41.3	2.7	6.0	23.8	23.0	-16.0	26.3
July-04	6.6	3.5	6.0	24.6	10.6	-6.1	-8.5
Average	19.4	13.4	6.0	13.2	28.0	-2.3	25.5
Percentage of water in	50	35	15	--	--	--	--
Percentage of water out	--	--	--	32	68	--	--

ment of ice cover on the lake. As ice pushes onshore, erosion can result. A high winter stage can increase this erosion, and consequently, WVIC drops stage early in the winter season (Federal Energy Regulatory Commission, 1996). The experimental maximum stage of 1,680.73 ft above NGVD 29 may further reduce winter stage and consequently shoreline erosion. Another possible result of a lower winter stage may be that spring flood damage is minimized if runoff is rapid or unusually heavy.

Table 14. Gaged and ungaged areas of streams tributary to Lac Vieux Desert, Michigan and Wisconsin.

[mi^2, square miles; --, no applicable data for this parameter; $ft^3/s/mi^2$, cubic feet per second per square mile; average runoff is in cubic feet per second, ft^3/s; a.n., assumed negligible; all areas delineated from U.S. Geological Survey 7.5-minute quadrangle maps]

	Misery Creek (05390062)	Misery Creek (05390064)	Misery Creek-combined	Scaup Lake Outlet	Marsh Bay Creek	Lobischer Creek	Unnamed Tributary on south shore of Lac Vieux Desert	Average
Gaged area (mi^2)	2.3	4.5	--	1.1	3.6	4.4	2.7	--
Ungaged area (mi^2)	2.4	.2	--	.2	1.2	.6	.20	--
Total area (mi^2)	4.7	4.7	4.7	1.3	4.8	5.0	2.9	--
Percentage of total gaged area (mi^2)	--	--	22	7	24	29	18	--
Runoff (area under base-flow conditions) ($ft^3/s/mi^2$)	.02	.44	.30	--	.12	.33	.29	0.24
Estimated average run-off for gaged part of stream basins (ft^3/s)	.11	2.06	1.40	a.n.	.56	1.64	.84	--

Table 15. Calculated evaporation rates for May through October for lakes in northern Wisconsin (Wentz and Rose, 1991; Robertson and Rose, 2000; Lenters and others, 2005).

[All evaporation rates are units of inch per day]

	Vandercook Lake (1981-83)	Lake Clara (1981-83)	Muskellunge Lake (12-year record)	Rainbow Reservoir (1949-79)	Sparkling Lake (1989-98)	Monthly average evaporation
May	0.12	0.13	0.12	0.12	0.13	0.12
June	.14	.14	.13	.14	.12	.13
July	.14	.13	.13	.14	.14	.14
August	.14	.14	.14	.12	.13	.13
September	.10	.11	.10	.10	.12	.11
October	.08	.09	.08	.08	.09	.08
Average daily evaporation for season	.12	.12	.12	.12	.12	.12

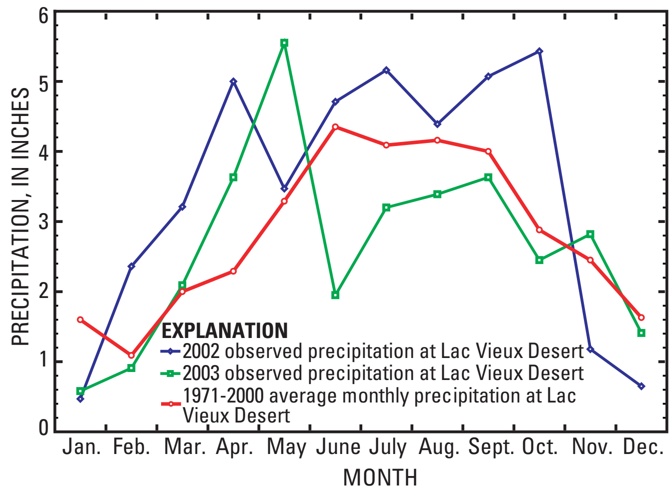


Figure 16. Observed monthly precipitation at Lac Vieux Desert, Michigan and Wisconsin, for 2002-03 compared with 30-year average monthly precipitation for the period 1971-2000 (Brian Hahn, National Oceanic and Atmospheric Administration, written commun., 2004).

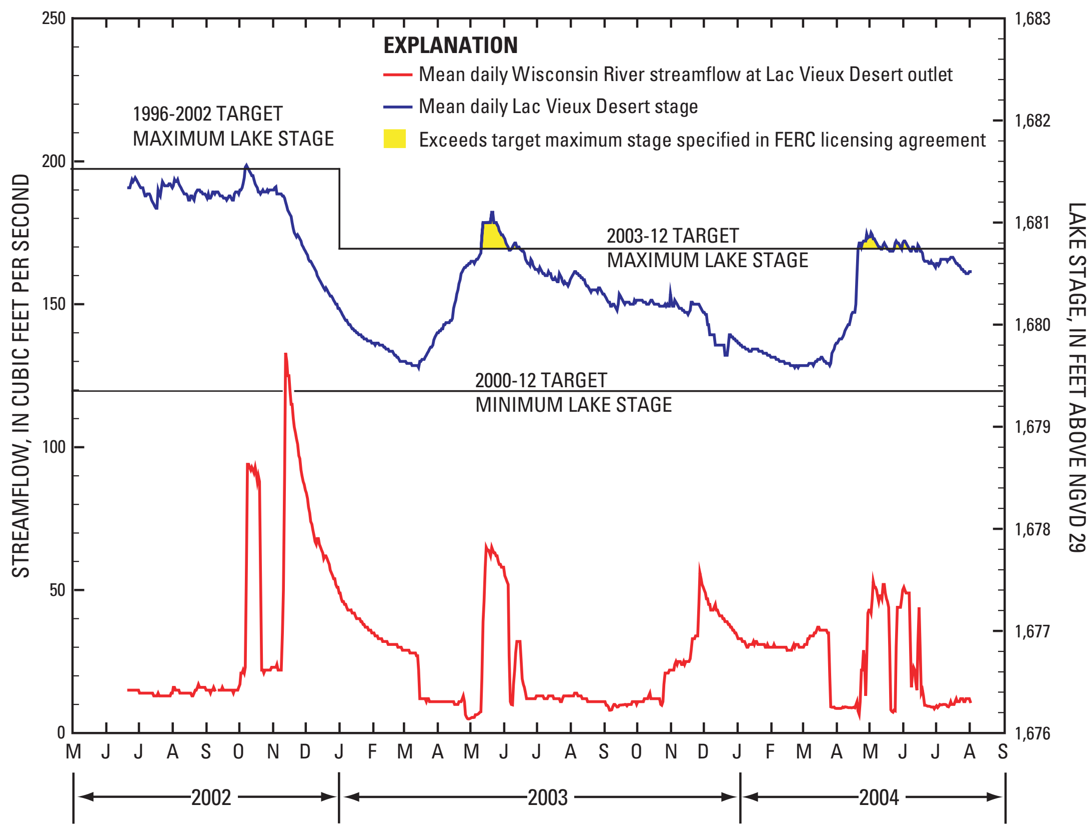


Figure 17. Mean daily streamflow of Wisconsin River at Lac Vieux Desert outlet and mean daily Lac Vieux Desert stage, Michigan and Wisconsin, June 2002 through September 2004.

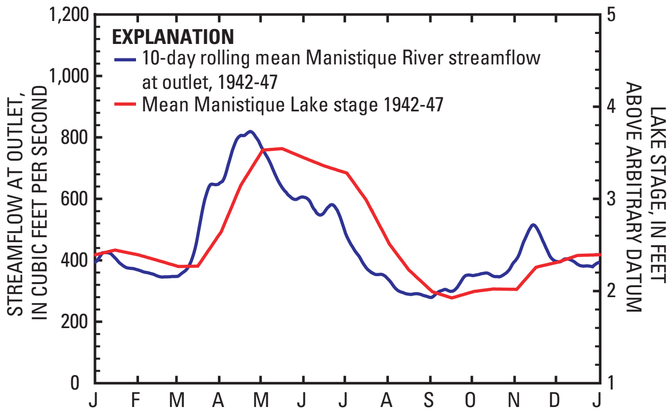


Figure 18. 10-day rolling mean Manistique River streamflow at outlet and mean Manistique Lake stage, Michigan, 1942-47.

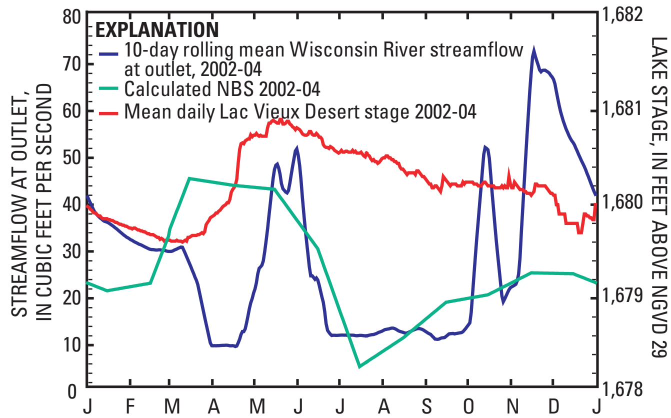


Figure 19. 10-day rolling mean Wisconsin River streamflow at outlet, calculated net basin supply (NBS), and mean daily Lac Vieux Desert stage, Michigan and Wisconsin, 2002-04.

Figure 20. Aerial photograph showing the east part of Rice Bay, Lac Vieux Desert, Gogebic County, Michigan, looking east August 2005. Photgraph by Great Lakes Indian Fish and Wildlife Commission. (Wild rice is the planar, bright green area from the shore into the bay and the streams are Scaup Lake outlet, upper center, and Marsh Bay Creek, upper right.)

Figure 21. Aerial photograph showing the northwest part of Misery Bay, Lac Vieux Desert, Gogebic County, Michigan, looking northeast August 2005. Photgraph by Great Lakes Indian Fish and Wildlife Commission. (Wild rice is the planar, bright green area and the stream is Misery Bay Creek.)

Table 16. Acreage of wild rice growing in Lac Vieux Desert, Gogebic County, Michigan, 2000 through 2004 (Great Lakes Indian Fish and Wildlife Commission, 2005).

[all numbers are acres; --, no appreciable wild rice growth during this year]

Year	Rice Bay	Misery Bay
2000	11	4.8
2001	15.8	4.7
2002	25.4	--
2003	25.4	2.3
2004	40.7	4.9

Summary and Conclusions

To evaluate the water quality and hydrology of the Lac Vieux Desert watershed and address tribal concerns, the U.S. Geological Survey, in cooperation with the Lac Vieux Desert Band of Lake Superior Chippewa Indians, conducted a study during 2002-04.

Water-quality samples were collected at 10 sites on the lake. Water-quality sampling was done twice per year, once shortly after ice-out in the spring and once before fall turnover, through August 2004. The water-quality characteristics of LVD are typical of many lakes with deep basins in the northern Midwest, with the exception that LVD does not typically stratify for long periods during summer months. Based on Trophic State Index calculations, LVD is classified as a highly productive eutrophic lake.

The pH of water in LVD ranged from 6.5 to 9.5, and specific conductance ranged from 62 to 114 µs/cm. Chloride concentration was less than 1.5 mg/L, indicating little effect from septic-tank or road-salt input. The water can be classified as soft (Hem, 1985), with hardness concentrations reported as calcium carbonate ranging from 29 to 49 mg/L. Concentrations of calcium, magnesium, chloride, and other dissolved solids (residue on evaporation) ranged from 47 to 77 mg/L. Alkalinity ranged from 27 to 38 mg/L.

Pervasive aquatic blooms, including the bloom noted during the September 2003 sampling, are apparently common in late summer. Biological productivity at LVD does not appear to have changed appreciably between 1973 and 2004. In the current study, total phosphorus concentrations ranged from 0.01 to 0.064 mg/L and dissolved nitrite plus nitrate nitrogen concentrations ranged from detection limit levels to 0.052 mg/L. Overabundance of nutrients in LVD, particularly nitrogen and phosphorus, could result in considerable degradation in lake-water quality.

Invasive species, including Eurasian Milfoil, may have had some effect on LVD, especially along the northern and western shores. Zebra mussels, which are common in many other lakes in the northern United States, were not detected during this study. Invasive species positively identified in LVD at the time of the study include the Rusty Crayfish and the fish parasite *Heterosporis*, which primarily affect native fauna.

The estimated water balance includes the following inputs to LVD from the surrounding watershed: direct precipitation (35 percent); runoff, composed of streamflow and overland flow (50 percent); and ground-water flow (15 percent). Outputs from LVD include streamflow into the Wisconsin River (68 percent) and evaporation from the lake surface (32 percent).

Seasonal regulation of LVD outflow results in an artificially high lake stage throughout the year, except from late winter to very early spring, prior to snowmelt and runoff. Regulation of LVD outflow causes Wisconsin River streamflow to be artificially low during spring and summer and artificially high in fall and winter. In addition, dam regulation alters seasonal fluctuations and limits interannual variability of LVD stage. Regulation of the dam affects the daily fluctuation of Wisconsin River streamflow. Lowering the target maximum stage of 1,681.53 ft to 1,680.73 ft above NGVD 29 (according to the current FERC licensing agreement) from 2003 through 2012 will have hydrologic effects. The primary net result of the lower target maximum stage is likely to be that outflow will increase in late spring and early summer and decrease during fall and winter.

Several independent factors may have affected wild-rice propagation at LVD during the time that a dam has been present at the site. These factors include, but are not limited to, lake-stage regulation and manipulation of the water-level regime, lack of viable seed stock, animal predation, competition from other macrophytes, and lake-bed sediment that may be too soft to protect and hold rice roots during high-energy wave action. Recent plantings of wild rice have been successful, indicating that suitable habitat and hydrologic regime were present in 2004-05.

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Appendix A.

Field water-quality parameters, major elements, solids, hardness, and nutrients in Lac Vieux Desert, Gogebic County, Michigan, and Vilas County, Wisconsin.

Appendix A. Field water-quality parameters, major elements, solids, hardness, and nutrients in Lac Vieux Desert, Gogebic County, Michigan, and Vilas County, Wisconsin.

[Site locations shown in figure 6; ft, feet; VOB, Secchi disk visible on lake bottom; NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO^3$, calcium carbonate; --, no data; <, less than; **, a general State of Michigan surface-water criterion has been established for this analyte; fil, filtered; N, nitrogen; E, estimated value; P, phosphorus; unfil, unfiltered; µg/L, micrograms per liter; M, presence of material verified but not quantified; ***,chlorophyll samples are composites collected through the water column from the surface to two times the depth of the photic zone]

Field water-quality parameter or constituent and units		Site 2 (4608470890525)				Site 3A (4608330890449)			
		5/14/02	9/24/02	5/14/03	9/9/03	5/15/02	9/25/02	5/14/03	9/8/03
Sampling depth	ft	3.5	3.5	4.0	3.0	14.0	13.5	14.0	12.0
Transparency (Secchi disk)	ft	4.3	5.0	3.4	3.8	4.5	5.3	4.5	4.0
Turbidity	NTU	3.4	3.9	2.9	7.5	7.9	4.1	7.8	7.5
Specific conductance	µs/cm	80	80	74	78	75	78	74	78
Water temperature	°C	8.0	13.5	11.5	23.0	8.0	13.0	10.0	18.5
pH	pH units	8.2	8.2	8.1	9.0	8.6	8.5	7.7	9.1
Dissolved oxygen	mg/L	12.4	8.4	12.2	10.1	11.8	8.9	11.2	8.6
Calcium	mg/L	9.08	9.86	9.11	10.9	8.89	9.50	9.58	9.00
Magnesium	mg/L	2.89	3.28	2.78	3.21	2.82	3.28	2.98	3.03
Sodium	mg/L	1.39	1.60	1.38	1.46	1.35	1.51	1.43	1.53
Alkalinity	mg/L as $CaCO^3$	35	37	34	36	34	35	34	37
Bicarbonate, fil	mg/L	43	45	41	39	42	42	42	39
Carbonate, fil	mg/L	--	--	--	2	--	--	--	3
Chloride	mg/L	1.34	1.00	.76	.77	1.01	.88	.81	.71
Fluoride	mg/L	<.10	<.10	<.17	<.20	<.10	<.10	<.17	<.20
Silica	mg/L	1.57	4.07	3.62	13.2	1.31	4.01	4.03	13.2
Sulfate	mg/L	2.4	2.0	2.0	1.8	2.4	2.0	2.1	1.9
** Residue on evaporation, 180°C	mg/L	53	50	51	62	71	51	52	62
Hardness	mg/L as $CaCO^3$	35	38	34	41	34	37	36	35
Nutrient and unit									
Ammonia, fil	mg/L as N	<.015	.028	<.015	<.015	<.015	E.011	.021	<.015
Ammonia + organic nitrogen, fil	mg/L as N	.37	.42	.33	.47	.37	.42	.38	.51
Nitrate + Nitrite, fil	mg/L as N	.015	E.009	<.022	<.022	<.013	<.013	<.022	<.022
Nitrite, fil	mg/L as N	.003	E.002	<.002	<.002	E.002	<.002	<.002	<.002
Phosphorus, fil	mg/L as P	.010	.007	.010	.009	.008	.006	.017	.013
Orthophosphate	mg/L as P	<.007	<.007	<.007	<.007	<.007	<.007	E.004	<.007
Phosphorus, unfil	mg/L as P	.038	.030	.035	.042	.036	.031	.046	.044
Boron, fil	µg/L	<13	M	<13	8.9	<13	E8.2	<13	9.4
Metal and unit									
Iron, fil	µg/L	160	30	166	24	150	34	141	27
Manganese, fil	µg/L	E1.7	M	6.3	.9	E2.2	e.9	3.5	1.3
***Chlorophyll									
Chlorophyll-a	µg/L	--	--	--	--	1.5	4.4	6.5	3.7
Chlorophyll-b	µg/L	--	--	--	--	<.1	<.1	<.1	<.1

Appendix A. Field water-quality parameters, major elements, solids, hardness, and nutrients in Lac Vieux Desert, Gogebic County, Michigan, and Vilas County, Wisconsin--continued.

[Site locations shown in figure 6; ft, feet; VOB, Secchi disk visible on lake bottom; NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO^3$, calcium carbonate; --, no data; <, less than; **, a general State of Michigan surface-water criterion has been established for this analyte; fil, filtered; N, nitrogen; E, estimated value; P, phosphorus; unfil, unfiltered; µg/L, micrograms per liter; M, presence of material verified but not quantified; ***,chlorophyll samples are composites collected through the water column from the surface to two times the depth of the photic zone; nutrient concentrations in parentheses for site 5A were collected at the mid-hypolimnion at 35 ft depth]

Field water-quality parameter or Constituent and units		Site 5A (4607260890650)							
		5/15/02	9/25/02	5/15/03	9/9/03	5/11/04	5/11/04	8/3/04	8/3/04
Sampling depth	ft	22.0	19.0	19.0	20.0	3.0	39.0	3.0	38.0
Transparency (Secchi disk)	ft	4.4	4.4	4.5	4.0	6.5	6.5	7.0	7.0
Turbidity	NTU	4.3	6.4	5.2	4.7	--	--	25.7	--
Specific conductance	µs/cm	79	78	78	77	74	74	78	114
Water temperature	°C	7.5	14.0	10.0	19.0	11.5	11.1	23.2	15.8
pH	pH units	8.2	8.2	7.4	7.1	7.2	7.0	7.8	6.5
Dissolved oxygen	mg/L	11.3	8.4	9.0	5.6	10.1	9.4	8.1	.37
Calcium	mg/L	9.53	9.55	9.36	9.06	9.11	--	--	--
Magnesium	mg/L	3.05	3.28	2.94	3.02	2.69	--	--	--
Sodium	mg/L	1.45	1.52	1.41	1.58	1.44	--	--	--
Alkalinity	mg/L as $CaCO^3$	36	35	36	37	32	--	34	
Bicarbonate, fil	mg/L	44	43	44	45	38	--	41	--
Carbonate, fil	mg/L	--	--	--	--	--	--	--	--
Chloride	mg/L	1.19	.76	1.47	.81	.85	--	--	--
Fluoride	mg/L	<.10	<.10	<.17	<.20	<.17	--	--	--
Silica	mg/L	1.56	4.18	3.98	13.6	12.5	--	--	--
Sulfate	mg/L	2.4	2.1	2.0	1.9	3.41	--	--	--
** Residue on evaporation, 180°C	mg/L	56	55	61	66	62	--	50	--
Hardness	mg/L as $CaCO^3$	36	37	35	35	34	--	--	--
Nutrient and units									
Ammonia, fil	mg/L as N	<.015	E.009	<.015	E.014	<.01	<.01	<.01	.24 (E.008)
Ammonia + organic nitrogen, fil	mg/L as N	.41	.41	.37	.41	.32	.27	.18	.56 (.34)
Nitrate + Nitrite, fil	mg/L as N	.051	<.013	<.022	<.022	<.016	<.016	<.016	<.016 (<.016)
Nitrite, fil	mg/L as N	.004	<.002	<.002	<.002	<.002	<.002	<.002	<.002 (<.002)
Phosphorus, fil	mg/L as P	.007	.005	.009	.010	.011	.008	E.005	.010 (.011)
Orthophosphate	mg/L as P	<.007	<.007	<.007	<.007	<.006	<.006	<.006	<.006 (<.006)
Phosphorus, unfil	mg/L as P	.035	.044	.038	.046	.022	.010	.031	.022 (.027)
Boron, fil	µg/L	<13	E7.3	<13	11	7.18	--	7.81	--
Metal and units									
Iron, fil	µg/L	188	22	110	30	56.3	--	--	--
Manganese, fil	µg/L	E1.1	E1.4	5.4	10.2	4.12	--	--	--
***Chlorophyll									
Chlorophyll-a	µg/L	10.7	8.9	5.9	5.9	8.2	--	E.80	--
Chlorophyll-b	µg/L	1.1	<.1	<.1	.7	<.1	--	<.1	--

Appendix A. Field water-quality parameters, major elements, solids, hardness, and nutrients in Lac Vieux Desert, Gogebic County, Michigan, and Vilas County, Wisconsin--continued.

[Site locations shown in figure 6; ft, feet; VOB, Secchi disk visible on lake bottom; NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO^3$, calcium carbonate; --, no data; <, less than; **, a general State of Michigan surface-water criterion has been established for this analyte; fil, filtered; N, nitrogen; E, estimated value; P, phosphorus; unfil, unfiltered; µg/L, micrograms per liter; M, presence of material verified but not quantified; ***,chlorophyll samples are composites collected through the water column from the surface to two times the depth of the photic zone]

Field water-quality parameter or Constituent and units		Site 7 (4608510890404)				Site 8 (4607140890904)			
		5/15/02	9/25/02	5/14/03	9/8/03	5/16/02	9/26/02	5/13/03	9/9/02
Sampling depth	ft	1.5	2.0	2.0	1.5	2.5	2.5	2.0	1.5
Transparency (Secchi disk)	ft	VOB	VOB	3.6	VOB	4.0	4.0	3.2	VOB
Turbidity	NTU	3.3	7.0	2.8	5.6	5.8	13	8.9	4.6
Specific conductance	µs/cm	70	77	62	82	79	77	74	76
Water temperature	°C	9.0	12.5	11.5	21.5	8.0	13.0	12.5	21.5
pH	pH units	8.3	8.5	8.0	9.5	8.3	8.1	8.2	9.1
Dissolved oxygen	mg/L	11.8	8.7	10.6	12.6	11.1	8.0	11.2	10.9
Calcium	mg/L	8.47	9.58	7.72	9.53	9.29	9.44	8.95	8.90
Magnesium	mg/L	2.73	3.29	2.37	3.20	2.98	3.22	2.82	2.97
Sodium	mg/L	1.31	1.54	1.22	1.59	1.40	1.52	1.37	1.50
Alkalinity	mg/L as $CaCO^3$	32	35	27	36	35	34	33	35
Bicarbonate, fil	mg/L	39	43	33	33	42	42	40	37
Carbonate, fil	mg/L	--	--	--	5	--	--	--	2
Chloride	mg/L	.73	.83	.58	.59	.95	.81	.87	.71
Fluoride	mg/L	<.10	<.10	<.17	<.20	<.10	<.10	<.17	<.20
Silica	mg/L	1.36	3.85	3.72	12.6	1.33	4.09	3.44	13.4
Sulfate	mg/L	2.4	2.1	1.9	1.8	2.4	2.0	1.9	1.9
** Residue on evaporation, 180°C	mg/L	53	57	53	63	56	56	47	68
Hardness	mg/L as $CaCO^3$	32	37	29	37	35	37	34	34
Nutrient and units									
Ammonia, fil	mg/L as N	<.015	E.012	<.015	<.015	<.015	.023	<.015	<.015
Ammonia + organic nitrogen, fil	mg/L as N	.42	.45	.41	.52	.42	.45	.41	.43
Nitrate + Nitrite, fil	mg/L as N	<.013	<.013	<.022	<.022	.036	<.013	<.022	<.022
Nitrite, fil	mg/L as N	<.002	E.002	<.002	<.002	.003	<.002	<.002	<.002
Phosphorus, fil	mg/L as P	.009	.008	.010	.010	.008	.006	.010	.011
Orthophosphate	mg/L as P	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007
Phosphorus, unfil	mg/L as P	.059	.021	.030	.029	.049	.021	.030	.049
Boron, fil	µg/L	<13	<13	E11	9.8	<13	E6.4	<13	10
Metal and units									
Iron, fil	µg/L	146	28	152	63	157	28	153	54
Manganese, fil	µg/L	8.1	E1.4	14.8	3.2	3.3	13.3	9.9	2.9
***Chlorophyll									
Chlorophyll-a	µg/L	--	--	--	--	--	--	--	--
Chlorophyll-b	µg/L	--	--	--	--	--	--	--	--

Appendix A. Field water-quality parameters, major elements, solids, hardness, and nutrients in Lac Vieux Desert, Gogebic County, Michigan, and Vilas County, Wisconsin--continued.

[Site locations shown in figure 6; ft, feet; VOB, Secchi disk visible on lake bottom; NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO^3$, calcium carbonate; --, no data; <, less than; **, a general State of Michigan surface-water criterion has been established for this analyte; fil, filtered; N, nitrogen; E, estimated value; P, phosphorus; unfil, unfiltered; µg/L, micrograms per liter; M, presence of material verified but not quantified; ***,chlorophyll samples are composites collected through the water column from the surface to two times the depth of the photic zone]

Field water-quality parameter or Constituent and units		Site 12 (4609390890644)				Site 13 (4607300890425)			
		5/14/02	9/24/02	5/15/03	9/10/03	5/15/02	9/25/02	5/14/03	9/9/02
Sampling depth	ft	3.0	3.0	3.0	2.0	2.0	2.0	2.0	1.5
Transparency (Secchi disk)	ft	4.5	4.2	4.2	2.0	VOB	VOB	VOB	VOB
Turbidity	NTU	2.6	4.7	3.7	17	4.6	9.0	3.7	3.4
Specific conductance	µs/cm	80	81	71	82	75	82	71	95
Water temperature	°C	7.5	14.5	12.0	22.5	9.5	12.0	13.5	20.5
pH	pH units	7.7	8.2	8.0	8.8	8.2	8.2	8.0	8.1
Dissolved oxygen	mg/L	11.4	8.3	9.8	8.1	11.9	9.2	12.0	9.2
Calcium	mg/L	9.20	10.0	8.54	11.6	8.96	9.86	8.91	12.7
Magnesium	mg/L	2.92	3.30	2.66	3.40	2.88	3.54	2.76	4.31
Sodium	mg/L	1.37	1.55	1.27	1.50	1.38	1.63	1.35	1.85
Alkalinity	mg/L as $CaCO^3$	33	37	29	38	36	37	31	43
Bicarbonate, fil	mg/L	40	45	36	43	44	45	38	53
Carbonate, fil	mg/L	--	--	--	1	--	--	--	--
Chloride	mg/L	1.43	1.25	.72	.68	.79	.81	.73	.80
Fluoride	mg/L	<.10	<.10	<.17	<.20	<.10	<.10	<.17	<.20
Silica	mg/L	1.79	3.93	3.90	13.6	1.78	6.04	4.21	14.0
Sulfate	mg/L	2.4	1.9	2.0	2.0	2.5	2.4	2.2	2.8
** Residue on evaporation, 180°C	mg/L	55	59	67	77	50	61	51	74
Hardness	mg/L as $CaCO^3$	35	39	32	43	34	39	34	49
Nutrient and units									
Ammonia, fil	mg/L as N	<.015	<.015	E.014	<.015	<.015	<.015	<.015	<.015
Ammonia + organic nitrogen, fil	mg/L as N	.47	.39	.43	.49	.42	.41	.40	.38
Nitrate + Nitrite, fil	mg/L as N	.052	<.013	<.022	<.022	.021	<.013	<.022	<.022
Nitrite, fil	mg/L as N	.003	<.002	<.002	<.002	.003	E.002	<.002	<.002
Phosphorus, fil	mg/L as P	.010	.005	.011	.009	.009	.007	.010	.009
Orthophosphate	mg/L as P	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007
Phosphorus, unfil	mg/L as P	.035	.034	.037	.064	.039	.025	.034	.038
Boron, fil	µg/L	<13	E8.5	<13	9.3	<13	<13	E9.1	8.6
Metal and units									
Iron, fil	µg/L	173	18	159	59	152	37	134	39
Manganese, fil	µg/L	3.9	4.0	19.9	12.8	6.7	E1.9	10.0	5.9
***Chlorophyll									
Chlorophyll-a	µg/L	--	--	--	--	--	--	--	--
Chlorophyll-b	µg/L	--	--	--	--	--	--	--	--

Appendix A. Field water-quality parameters, major elements, solids, hardness, and nutrients in Lac Vieux Desert, Gogebic County, Michigan, and Vilas County, Wisconsin--continued.

[Site locations shown in figure 6; ft, feet; VOB, Secchi disk visible on lake bottom; NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO^3$, calcium carbonate; --, no data; <, less than; **, a general State of Michigan surface-water criterion has been established for this analyte; fil, filtered; N, nitrogen; E, estimated value; P, phosphorus; unfil, unfiltered; µg/L, micrograms per liter; M, presence of material verified but not quantified; ***,chlorophyll samples are composites collected through the water column from the surface to two times the depth of the photic zone]

		Site 14 (4609030890733)				Site 15 (4608460890510)		Lac Vieux Desert @outlet (4607170890909)	
Field water-quality parameter or Constituent and units		**5/12/04**	**5/12/04**	**8/2/04**	**8/2/04**	**5/11/04**	**8/3/04**	**5/12/04**	**8/2/04**
Sampling depth	ft	3.0	13.0	3.0	12.0	3.0	3.0	1.5	2
Transparency (Secchi disk)	ft	7.0	7.0	5.7	5.7	7.0	VOB	VOB	VOB
Turbidity	NTU							2.75	20.6
Specific conductance	µs/cm	72	74	79	81	72	79	76	79
Water temperature	°C	13.0	12.3	23.6	21.6	13.0	23.0	14.8	23.0
pH	pH units	7.4	6.8	7.8	7.2	7.4	8.2	7.1	7.7
Dissolved oxygen	mg/L	10.1	9.3	8.1	5.9	10.1	9.2	10.0	7.9
Calcium	mg/L	--	--	--	--	--	--	9.22	--
Magnesium	mg/L	--	--	--	--	--	--	2.71	--
Sodium	mg/L	--	--	--	--	--	--	1.47	--
Alkalinity	mg/L as $CaCO^3$	32	--	34	--	32	34	33	36
Bicarbonate, fil	mg/L	39	--	40	--	40	40	40	43
Carbonate, fil	mg/L	--	--	--	--	--	--	--	--
Chloride	mg/L	--`	--	--	--	--	--	.93	--
Fluoride	mg/L	--	--	--	--	--	--	<.17	--
Silica	mg/L	--	--	--	--	--	--	12.4	--
Sulfate	mg/L	--	--	--	--	--	--	3.4	--
** Residue on evaporation, 180°C	mg/L	--	--	--	--	--	--	57.1	--
Hardness	mg/L as $CaCO^3$	--	--	--	--	--	--	34	--
Nutrient and units									
Ammonia, fil	mg/L as N	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Ammonia + organic nitrogen, fil	mg/L as N	.28	.26	.32	.32	.30	.36	.30	.33
Nitrate + Nitrite, fil	mg/L as N	<.016	<.016	<.016	<.016	<.016	<.016	<.016	<.016
Nitrite, fil	mg/L as N	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.0029
Phosphorus, fil	mg/L as P	.007	.007	.010	E.010	.011	.013	.011	E.012
Orthophosphate	mg/L as P	<.006	<.006	<.006	<.006	<.006	<.006	<.006	E.003
Phosphorus, unfil	mg/L as P	.018	.020	.026	.026	.033	.022	.033	.032
Boron, fil	µg/L	--	--	--	--	--	--	7.19	--
Metal and units									
Iron, fil	µg/L	--	--	--	--	--	--	47.5	--
Manganese, fil	µg/L	--	--	--	--	--	--	15.8	--
***Chlorophyll									
Chlorophyll-a	µg/L	7.17	--	--	E2.47	5.41	E1.74	9.39	E29.2
Chlorophyll-b	µg/L	.29	--	--	--<.1	.30	-<.1-	.65	<.1

Appendix B.

Daily mean streamflow for the Wisconsin River near Land O' Lakes, Wisconsin, from June 2002 through September 2004.

U.S. DEPARTMENT OF THE INTERIOR - U.S. GEOLOGICAL SURVEY - WATER RESOURCES

STATION NUMBER 05390101 WISCONSIN RIVER NEAR LAND O LAKES, WI SOURCE AGENCY USGS STATE 55 COUNTY 125
LATITUDE 460718 LONGITUDE 0890907 NAD27 DRAINAGE AREA 34.4* CONTRIBUTING DRAINAGE AREA DATUM 1600 NGVD29 Date
Processed: 2005-11-18 08:58 By rlleuvoy
APPROVED
DD #2
Discharge, cubic feet per second
WATER YEAR OCTOBER 2001 TO SEPTEMBER 2002
DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	---	---	---	---	---	---	---	---	---	16	18	15
2	---	---	---	---	---	---	---	---	---	16	18	16
3	---	---	---	---	---	---	---	---	---	16	17	15
4	---	---	---	---	---	---	---	---	---	15	17	14
5	---	---	---	---	---	---	---	---	---	15	17	15
6	---	---	---	---	---	---	---	---	---	14	17	16
7	---	---	---	---	---	---	---	---	---	14	16	16
8	---	---	---	---	---	---	---	---	---	15	14	16
9	---	---	---	---	---	---	---	---	---	14	15	e16
10	---	---	---	---	---	---	---	---	---	14	15	e15
11	---	---	---	---	---	---	---	---	---	13	14	e16
12	---	---	---	---	---	---	---	---	---	13	15	16
13	---	---	---	---	---	---	---	---	---	13	15	15
14	---	---	---	---	---	---	---	---	---	12	15	16
15	---	---	---	---	---	---	---	---	---	12	14	16
16	---	---	---	---	---	---	---	---	---	12	14	15
17	---	---	---	---	---	---	---	---	---	12	14	15
18	---	---	---	---	---	---	---	---	---	14	13	14
19	---	---	---	---	---	---	---	---	---	14	13	15
20	---	---	---	---	---	---	---	---	---	13	13	15
21	---	---	---	---	---	---	---	---	16	14	15	15
22	---	---	---	---	---	---	---	---	15	14	16	14
23	---	---	---	---	---	---	---	---	17	12	16	15
24	---	---	---	---	---	---	---	---	17	12	17	15
25	---	---	---	---	---	---	---	---	17	13	17	14
26	---	---	---	---	---	---	---	---	17	13	17	15
27	---	---	---	---	---	---	---	---	18	12	17	15
28	---	---	---	---	---	---	---	---	17	12	17	15
29	---	---	---	---	---	---	---	---	17	14	16	15
30	---	---	---	---	---	---	---	---	17	15	17	16
31	---	---	---	---	---	---	---	---	---	16	16	---
TOTAL	---	---	---	---	---	---	---	---	---	424	485	456
MEAN	---	---	---	---	---	---	---	---	---	13.7	15.6	15.2
MAX	---	---	---	---	---	---	---	---	---	16	18	16
MIN	---	---	---	---	---	---	---	---	---	12	13	14
CFSM	---	---	---	---	---	---	---	---	---	0.4	0.45	0.44
IN.	---	---	---	---	---	---	---	---	---	0.46	0.52	0.49

U.S. DEPARTMENT OF THE INTERIOR - U.S. GEOLOGICAL SURVEY - WATER RESOURCES

STATION NUMBER 05390101 WISCONSIN RIVER NEAR LAND O LAKES, WI SOURCE AGENCY USGS STATE 55 COUNTY 125
LATITUDE 460718 LONGITUDE 0890907 NAD27 DRAINAGE AREA 34.4* CONTRIBUTING DRAINAGE AREA DATUM 1600 NGVD29 Date Processed: 2005-11-18 08:58 By rlleuvoy
APPROVED
DD #2
Discharge, cubic feet per second
WATER YEAR OCTOBER 2002 TO SEPTEMBER 2003
DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	17	23	84	49	35	29	11	5.3	55	13	13	11
2	21	23	82	47	34	29	11	5.5	54	13	13	9.7
3	21	23	79	46	e34	29	11	5.4	53	13	13	9.7
4	22	24	77	46	e34	29	11	5.5	52	13	14	9.2
5	21	e22	74	45	e33	29	11	6.4	27	13	14	8
6	23	e22	73	45	e33	28	11	6.4	11	13	14	8
7	59	e22	71	44	e33	28	11	6.5	10	12	13	8.1
8	94	e22	69	43	e33	28	11	6.8	9.9	12	13	9.2
9	94	e35	67	43	e32	28	11	7.2	17	12	13	10
10	93	e50	66	43	e32	28	11	7.4	22	12	13	10
11	92	e90	68	43	e32	28	11	19	28	13	12	9.5
12	93	e133	68	42	e32	27	11	39	32	13	12	9.1
13	92	e130	66	42	e32	27	11	46	32	13	12	9.2
14	91	e125	65	42	e31	22	11	58	32	13	12	9.7
15	93	e125	64	41	e31	12	11	65	32	13	12	9.8
16	91	e120	63	40	e31	12	10	64	25	12	11	9.8
17	88	e115	61	40	e31	12	10	64	19	12	11	9.9
18	90	e115	62	40	e31	12	10	63	17	12	11	9.9
19	88	e110	62	40	31	12	10	62	16	12	11	10
20	57	e107	61	39	31	12	11	65	14	12	11	10
21	22	105	60	39	31	11	11	64	12	12	11	9.5
22	22	103	59	38	31	12	11	63	12	11	11	10
23	21	101	57	38	30	12	12	63	12	11	11	10
24	22	97	56	37	30	11	13	62	12	12	11	10
25	22	96	55	37	30	11	11	62	12	13	11	10
26	22	92	54	37	30	11	6.4	60	12	13	11	11
27	22	90	54	36	29	11	5.5	59	12	13	11	11
28	22	88	52	36	29	11	5	59	12	13	11	11
29	22	87	51	36	---	11	4.9	58	12	13	11	11
30	23	85	51	35	---	11	5.1	58	13	13	11	10
31	23	---	49	35	---	11	---	58	---	13	11	---
TOTAL	1583	2380	1980	1264	886	584	300.9	1273.4	678.9	388	369	293.3
MEAN	51.1	79.3	63.9	40.8	31.6	18.8	10	41.1	22.6	12.5	11.9	9.78
MAX	94	133	84	49	35	29	13	65	55	13	14	11
MIN	17	22	49	35	29	11	4.9	5.3	9.9	11	11	8
CFSM	1.48	2.31	1.86	1.19	0.92	0.55	0.29	1.19	0.66	0.36	0.35	0.28
IN.	1.71	2.57	2.14	1.37	0.96	0.63	0.33	1.38	0.73	0.42	0.4	0.32

U.S. DEPARTMENT OF THE INTERIOR - U.S. GEOLOGICAL SURVEY - WATER RESOURCES

STATION NUMBER 05390101 WISCONSIN RIVER NEAR LAND O LAKES, WI SOURCE AGENCY USGS STATE 55 COUNTY 125
LATITUDE 460718 LONGITUDE 0890907 NAD27 DRAINAGE AREA 34.4* CONTRIBUTING DRAINAGE AREA DATUM 1600 NGVD29 Date
Processed: 2005-11-18 08:58 By rlleuvoy
APPROVED
DD #2
Discharge, cubic feet per second
WATER YEAR OCTOBER 2003 TO SEPTEMBER 2004
DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	11	22	50	33	30	30	8.6	43	51	9.5	11	9.3
2	11	22	49	33	30	31	8.6	42	50	8.9	11	9.6
3	11	22	47	33	31	31	8.6	47	49	9.3	12	10
4	11	24	47	33	30	31	8.6	53	49	10	12	11
5	11	25	45	32	30	33	8.7	51	49	9.9	12	11
6	11	24	45	32	30	33	9.1	51	49	9.9	12	11
7	12	25	43	32	30	34	8.9	50	31	10	12	11
8	12	25	43	31	30	34	9.2	48	16	10	12	12
9	12	25	43	30	30	34	9.1	46	21	10	12	12
10	12	24	44	30	30	34	9	48	23	9.9	14	12
11	13	24	45	31	30	35	8.9	48	22	9.3	14	13
12	14	25	43	31	30	35	8.9	47	18	9.2	13	12
13	12	24	43	31	30	36	8.9	52	15	9.7	9.3	13
14	12	25	42	31	30	37	8.8	52	31	11	9.1	13
15	12	25	41	32	29	37	8.9	49	44	10	9.1	14
16	12	25	41	31	29	36	9	47	28	10	9.5	14
17	12	25	41	32	29	36	8.8	46	14	10	9.8	14
18	12	26	40	32	29	36	9.8	44	15	11	11	14
19	12	29	40	31	29	36	11	30	13	12	11	15
20	12	33	39	31	30	36	7.7	8.1	9.7	11	11	15
21	12	33	39	31	31	36	6.5	7.6	9.7	11	11	15
22	10	33	39	31	30	36	11	7.3	9.5	11	12	15
23	9.7	34	38	31	31	35	22	8	9.4	12	9.6	15
24	11	34	38	31	31	35	22	7.8	9.4	12	6.8	15
25	17	34	37	31	31	20	29	30	9.3	12	6.8	16
26	21	45	37	30	30	9.2	25	44	9.1	11	6.7	16
27	21	56	36	30	30	9	13	44	9.1	11	7.4	17
28	21	54	36	31	30	9	26	44	9.1	12	8.2	16
29	21	52	35	30	30	9.1	42	44	8.5	12	8.5	16
30	22	51	35	30	---	8.7	43	47	9.1	12	9	16
31	22	---	34	30	---	8.6	---	50	---	12	9.2	---
TOTAL	424.7	925	1275	968	870	900.6	418.6	1235.8	689.9	328.6	322	402.9
MEAN	13.7	30.8	41.1	31.2	30	29.1	14	39.9	23	10.6	10.4	13.4
MAX	22	56	50	33	31	37	43	53	51	12	14	17
MIN	9.7	22	34	30	29	8.6	6.5	7.3	8.5	8.9	6.7	9.3
CFSM	0.4	0.9	1.2	0.91	0.87	0.84	0.41	1.16	0.67	0.31	0.3	0.39
IN.	0.46	1	1.38	1.05	0.94	0.97	0.45	1.34	0.75	0.36	0.35	0.44
CAL YR	2003	TOTAL	8662.2	MEAN	23.7	MAX	65	MIN	4.9	CFSM	0.69	IN. 9.37
WTR YR	2004	TOTAL	8761.1	MEAN	23.9	MAX	56	MIN	6.5	CFSM	0.7	IN. 9.47

Appendix C.

Legal lake stage at Lac Vieux Desert, Gogebic County, Michigan, and Vilas County, Wisconsin (a summary of Federal Energy Regulatory Commission licensing agreement with Wisconsin Valley Improvement Company for the outlet dam at Lac Vieux Desert and legal lake stage).

Wisconsin Valley Improvement Company owns and operates the dam at the outlet of Lac Vieux Desert (LVD) and maintains lake stage under Federal Energy Regulatory Commission (FERC) licensing provisions (Federal Energy Regulatory Commission, 1996). Prior to 2003, lake stage was maintained within a 2.17 ft range, with a minimum altitude of 1,679.36 ft and a maximum altitude of 1,681.53 ft above NGVD 29 (except temporarily in cases of emergency or upon agreement with U.S. Fish and Wildlife Service and Wisconsin Department of Natural Resources). Timing of water release from LVD is monitored in accordance with FERC license requirements (Federal Energy Regulatory Commission, 1996). The specific operating rules for the Wisconsin River reservoir system are listed in FERC License No. 2113-022, issued July 17, 1996, and modified by an Order on Rehearing dated July 17, 1997 (Wisconsin Valley Improvement Corporation, 2004).

During the period 2003-12, lake stage will be maintained within a 1.37 ft range, as the maximum lake stage will be lowered from an altitude of 1,681.53 to 1,680.73 ft above NGVD 29 as part of an effort to restore wild rice (*zizania aquatica*) to LVD. The minimum lake stage for the period 2003-12 will remain unchanged at an altitude of 1,679.36 above NGVD 29 (U.S. Forest Service, 2004).

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Federal Energy Regulatory Commission, 1996, Order issuing new license for Wisconsin Valley Improvement Company, Wisconsin River, Project No. 2113-022, dated July 18, 1996.

U.S. Forest Service, 2004, Lac Vieux Desert wild rice plan: Prepared by U.S. Department of Agriculture, Forest Service in cooperation with nine other State and Federal Agencies and the Lac Vieux Desert Band of Lake Superior Chippewa Indian Tribe, Michigan, 9 p.

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USGS

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